Transactions of American Society for Steel Treating

Published Monthly Cleveland, September, 1922 Ten Dollars a Year

Vol. II *Entered as second-class matter Feb. 7, 1921, at the post-office at Cleveland, Ohio, under the Act of March 3, 1879* No. 12

CONVENTION ISSUE

SPECIAL FEATURES

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4600 Prospect Avenue

TRANSACTIONS
of the
American Society for Steel Treating

Vol. II Cleveland, September 1922 No. 12

ON TO DETROIT

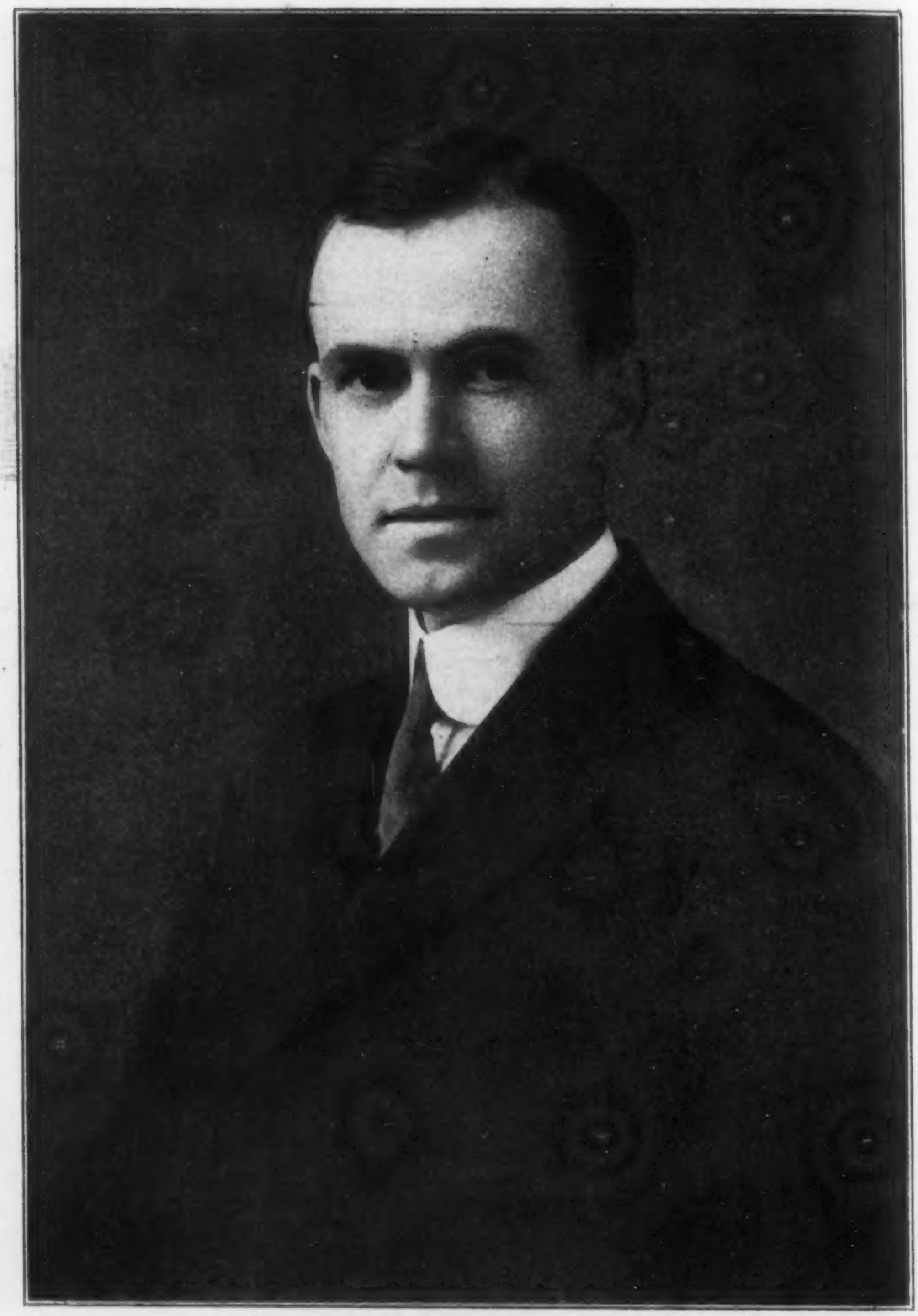
THE annual convention of the American Society for Steel Treating in Detroit the week of October 2nd gives promise of being the best attended of any of the three previous annual meetings. The large percentage of members who attend is remarkable and has occasioned much favorable comment. It is doubtful if any other technical society holding annual meetings has the same percentage of its membership present. There must be and is a reason for this. It is because those who have once attended find the accruing benefits so voluminous that it would be the height of folly to remain away. Not only have the attendants found real meat and satisfaction in the programs presented but the exposition has always made a lasting impression. Its educational value and the wonderful possibilities of observing at first hand the latest and best products, materials and equipment for their use serves as a magnet to draw them back to another convention. Nothing worth while is absent from the exposition because all progressive, wide awake firms are exhibiting. They represent the leaders in their lines just as those in attendance represent the leadership in the intellectual metallurgical thought of the country.

The annual meeting of the best minds at the A. S. S. T. convention is becoming more and more recognized as an essential part of the year's work. With the program and exposition increasing both in quality and scope the general benefits will of course be greatly enlarged and the attendance should grow at a greater rate in the future than in the past. Those who have attended previous conventions will be at Detroit. Those who have not owe it to themselves to step out with the leaders.

HARDNESS TESTING AND METALLURGICAL EDUCATION SYMPOSIUMS

WE ARE looking forward with much interest and expectation that the symposium on hardness testing to be held Thursday October 5th in connection with our convention, will accomplish some new and constructive contributions to this very important phase of metal inspection. The nomenclature, the methods employed in testing hardness of metal and the ultimate value of the results obtained in determining the quality or the fitness of a given part to function properly, are matters to be discussed during this session. The term hardness, being simply a relative term, requires defining as there are many misconceptions as to just what the property of hardness signifies in the constitution of a specimen of metal. Then too, the best and most rapid method of determining this property is of equal importance.

The merits of the various methods of testing hardness which are available will probably consume much of the time allowed for discussion. With the aid of the questionnaire which is published in this issue of TRANSACTIONS



FRANK P. GILLIGAN
National President of the American Society for Steel Treating

all those who are interested will have an opportunity to present their views of the various phases of hardness testing prior to this session with the result that a better organized discussion will obtain.

Under the able leadership of Major A. E. Bellis, chairman of this session, we look forward to having an interesting, instructive and constructive contribution to the data already available on the subject of hardness testing.

The symposium on metallurgical education scheduled for Tuesday, October 3rd, promises to be well attended. The purpose of this meeting will be "Not how but what to teach," and should command the interest of not only teachers but men who are in the industrial world in capacities, such that they consume each year in their departments, the product of the various educational institutions. After all is said, it is the observer in the industry who has the opportunity to see the points of weakness of the college graduates and the viewpoints of these men will be valuable in making this meeting a success and will augur well for its institution as a yearly event on our convention program. This surely is a step forward so why not all assist in making its action positive.

This meeting will be under the guidance of Prof. S. L. Goodale, of the University of Pittsburgh. Professor Goodale has had wide experience in the metallurgical instruction of young students and is sure to handle this meeting in a very commendable manner.

SATISFACTION

A LETTER received from a resigning member comments as follows: "I don't need the Society. I know enough about steel treating to hold a job any place."

While we realize that the fourth request for payment of dues may have been sufficient to arouse the recipient's anger and thus cause the sending of the above sentiments, yet we feel that the statement is worthy of notice. In no way disparaging the letter writer's ability, there is no doubt all are familiar with the type of individual to whom further knowledge is useless and who resents any effort to elevate him from the plane in which he lies. In reality he is satisfied with things as they are and dislikes any change in the old order of events.

His principal interest is in the time clock and pay envelope and while he may do his work satisfactorily—that will be all one can say of it for the incentive to do more and better is absent.

It is indeed deplorable and unfortunate not only for the employer but for the employee himself when that individual reaches the viewpoint in life: 'I don't need any help. I know enough."

The number of self-satisfied and self-centered individuals is amazing and we find them not only in the time clock but also in the salary division. Too many are willing to listen to the command, "at ease" or "as you were," when in order to progress and advance they should hear only the command, "Forward March!" Philip Brooks has written a thought with which all will agree: "Sad is the day for any man when he becomes absolutely satisfied with the life he is living, the thoughts that he is thinking and the deeds that he is doing; when there ceases to be forever beating at the doors of his soul a desire to do something larger which he feels and knows he was meant and intended to do."

HENRY MARION HOWE MEDAL

THE Board of Directors of the American Society for Steel Treating with the approval of Mrs. Howe has set aside a fund from the treasury of the Society to be known as the Henry Marion Howe Fund, the proceeds from which will apply on an annual medal to be known as the Henry Marion Howe Medal.

The medal will be of gold and will be presented to the author of the paper considered of highest merit on any subject within the field covered by the Society.

The establishment of this medal is a tribute to the exceptional contributions to the science of metallurgy made by the late Dr. Howe. In this way the Society will recall annually the achievements of its distinguished Honorary Member.

The rules governing the award of the medal will be announced during the International Steel Exposition and Convention of the Society to be held at Detroit, October 2-7.

THE EXPOSITION

FINAL arrangements are being made for the fourth International Steel Exposition and Conventions of the American Society for Steel Treating and the American Drop Forging Institute to be held in the General Motors Building, Detroit, Michigan, October 2-7.

The Exposition will be the largest ever held, as 99 per cent of the floor space has been sold and many exhibitors who desired to be present will be unable to be accommodated. There will be quite a number of exhibitors who have not been present at previous shows due to the fact that the Drop Forging Institute is holding its Annual Convention simultaneously and in the same building with the American Society for Steel Treating, and many members of the Drop Forging Supply Association are accepting the opportunity to exhibit.

The General Motors Building is especially adapted for exhibition purposes. In the large exhibition hall, there are 30,000 square feet, while the two wings on the same floor leading to the exhibition hall has 20,000 additional square feet of display space. All but a few booths have been sold. Arrangements have been made so that in one section of the hall gas furnaces will be in operation, while electrical furnaces and other equipment requiring power will be displayed throughout the hall. Practically all of the exhibits will be in operation.

At the three previous expositions held at Chicago, Philadelphia and Indianapolis, the attendance has been in excess of 10,000 and it is expected that because of the great interest in Detroit as a heat treating center, as well as a market for steel, the attendance will be in excess of 15,000.

The railroads have granted fare and one-half for the round trip to Detroit on account of the Conventions. In order to be able to take advantage of this reduced fare which applies not only to the holder of the certificate but to the members of his family as well, it is necessary that one should have an identification certificate. These may be obtained by addressing the National Secretary of the American Society for Steel Treating, Mr. W. H. Eisenman, 4600 Prospect Avenue, Cleveland, Ohio.

Certificates will be mailed to all members about Sept. 15th.

Reduced fare tickets may be purchased September 28, return limit being October 13th.

A complete list of exhibitors and floor plan is given on other pages.

PLANT VISITATION

Mr. W. B. Hurley, Chairman of the Plant Visitation Committee, is making arrangements for the visitation of the following plants:

Ford Motor Company (Highland Park Plant), Ford Motor Company (River Ridge Plant), Cadillac Motor Company, Central Forge & Gear Company, Lincoln Motor Car Company, Detroit Steel Products Company, Detroit Twist Drill Company, Hudson Motor Car Company.

There will be two sessions of plant visitors each day, both of them starting from the General Motors Building, the morning session at 10:00, and the afternoon session at 2:00. Plant visitation may be arranged on Tuesday, Wednesday, Thursday or Friday of Convention week. By this excellent and convenient arrangement, it will be possible for visitors to select the plant they wish to visit as well as arrange the time so that they will not miss any of the sessions in which they are particularly interested.

MEMORIAL TABLET

Probably one of the most interesting events to occur during the International Steel Exposition and Convention of the American Society for Steel Treating at Detroit, October 2nd to 7th will be the unveiling of a bronze tablet dedicated to the memory of those pioneers of the steel industry who in 1864 at Wyandotte, Michigan, erected the first Bessemer Steel Converter used commercially for the manufacture of Bessemer Steel in America.

This tablet is to be erected by the Detroit Chapter of the American Society for Steel Treating through its Executive Committee and Messrs. Atkinson, Hamilton and McCloud, acting as a special committee.

The site of the Wyandotte Iron Works where Kelly's first tilting Bessemer steel converter was erected is the present location of the Wyandotte Public Library and permission has been secured from the Library Board for the placing of this tablet on the front of the building.

The tablet will be 24 x 36 inches and at the head of it will be a bas-relief of the original converter.

The unveiling exercises will probably be held on Thursday afternoon, October 5, and the Governor of Michigan has indicated his intentions of being present, and other speakers of prominence are being invited and many have signified their intention to be present.

It is interesting to note that the erection of this tablet is the first public recognition of the achievements of William Kelly who made his first Bessemer steel in 1847 and finally patented his process in 1856 although it was eight years later before the Wyandotte Iron Works produced the first Bessemer steel for commercial purposes.

Shortly before Mr. Kelly's death he said to his children, "the day will come when someone will do me justice." It remained for the Detroit Chapter of the American Society for Steel Treating to commemorate the achievement of the early pioneers in the development of the process that caused the United States to become the supreme steel making nation in the world.

SYMPOSIUM ON METALLURGICAL EDUCATION

Owing to the requests from many members of the American Society for Steel Treating in the teaching profession that an opportunity should be given them to have a conference with metallurgical engineers who are engaged in commercial industries so that the universities and colleges might better prepare their students for the greatest usefulness, a symposium on metallurgical

education has been placed on the program of the convention of the American Society for Steel Treating at Detroit and will be held at 4:00 p. m., on Tuesday, Oct. 3. At this symposium it is not proposed to discuss "how to teach" metallurgy, but "what" metallurgical subjects should receive the greatest *emphasis*.

Professor S. L. Goodale, University of Pittsburgh, will be Chairman of the session, while others contributing to the symposium will be Howard J. Stagg, Assistant Manager of Halcomb Steel Company; H. B. Knowlton, Central Continuation School, Milwaukee; Professor John Keller, Iron and Steel Extension Department of Purdue University; Professor H. M. Boylston, Professor of Metallurgy, Case School of Applied Science; Dr. N. B. Hoffman, Metallurgist, Colonial Steel Company; Mr. McCleary, Metallurgist, Dodge Motor Car Company; Dr. John A. Mathews, President, Crucible Steel Company of America; Professor O. A. Knight, State College, Pa.; Professor Frederick Crabtree, Carnegie Institute of Technology; and Dr. C. M. Johnson, Crucible Steel Company of America; W. C. Peterson, Manager, Alloy Steel Division, Atlas Steel Corp., and many others.

This symposium on "Not How" but "What to Teach" is the first symposium on metallurgical education ever held in the United States and is expected to be productive of very desirable results and to be a regular feature of the future conventions of the American Society for Steel Treating.

SYMPOSIUM ON HARDNESS TESTING

The Hardness Committee of the National Research Council will hold an important symposium during the International Steel Exposition at Detroit, October 2nd to 7th.

This committee has already done a great amount of very valuable work on the subject of hardness testing and this meeting of the committee will undoubtedly have very important results.

The symposium will be in charge of Major A. E. Bellis, formerly Metallurgist, U. S. Armory, Springfield, and at present President, Bellis Heat Treating Company, New Haven.

The program will be as follows:

"Object of Committees, Investigation and Questionnaire," by Major A. E. Bellis, Chairman of Hardness Testing Committee.

"Significance of Hardness Tests," by Dr. H. P. Hollnagel, General Electric Company.

"Hardness and Its Relation to Magnetic Properties," by Professor R. S. Williams, Oberlin College.

"Discussion of Methods of Hardness Testing."

ANNUAL BANQUET

The Annual Banquet of the American Society for Steel Treating and the American Drop Forging Institute will be held jointly in the ball room of the Statler Hotel during the International Steel Exposition and Conventions of the two societies at Detroit, October 2nd to 7th.

The date of the banquet is Thursday evening, October 5. The doors will be open at 6:30 and banquet will be served at 7:00.

Mr. C. F. Kettering, President of the Dayton Engineering Laboratories Company and a member of the American Society for Steel Treating since its organization, will serve as toastmaster. President Burton of the University of Michigan, one of the best dinner speakers in the country, will address the

banqueters. There will be other speakers of national prominence including the Governor of Michigan and some chief executives of the largest steel companies in the country.

The number of banqueters will be limited to 1000.

ENTERTAINMENT

Plans have been made by the Detroit Chapter for the entertainment of members and guests of the American Society for Steel Treating and the American Drop Forging Institute when they hold their convention in Detroit during the International Steel Exposition, General Motors Building, October 2nd to 7th.

Monday evening, October 2nd, has been left open in order that the visitors may have the opportunity to thoroughly study the exhibits which will be the most extensive ever shown.

On Tuesday evening, October 3rd, beginning at 9:30, Mr. Frank G. Davis, Chairman of the Entertainment Committee, with the assistance of the Detroit Chapter will give a smoker in the large Auditorium of the General Motors Building.

On Wednesday evening, October 4th, beginning at 9:00 in the main auditorium of the General Motors Building, the Detroit Chapter will hold a Carnival, Frolic and Dance for the members of the Society and their guests. All of the entertainment features of a Carnival as well as the necessary adjuncts for a joyous frolic will be on hand. Not the least in importance at the carnival and frolic will be the two high grade orchestras providing music for the dancers.

On Thursday evening, October 5th, will be the Annual Banquet at the Statler Hotel at which speakers of national prominence will be present and at which, because of the size of the banquet hall, only 1000 will be able to attend.

LADIES' ENTERTAINMENT

The entertainment of the ladies has always been one of the most successful events of the conventions of the American Society for Steel Treating.

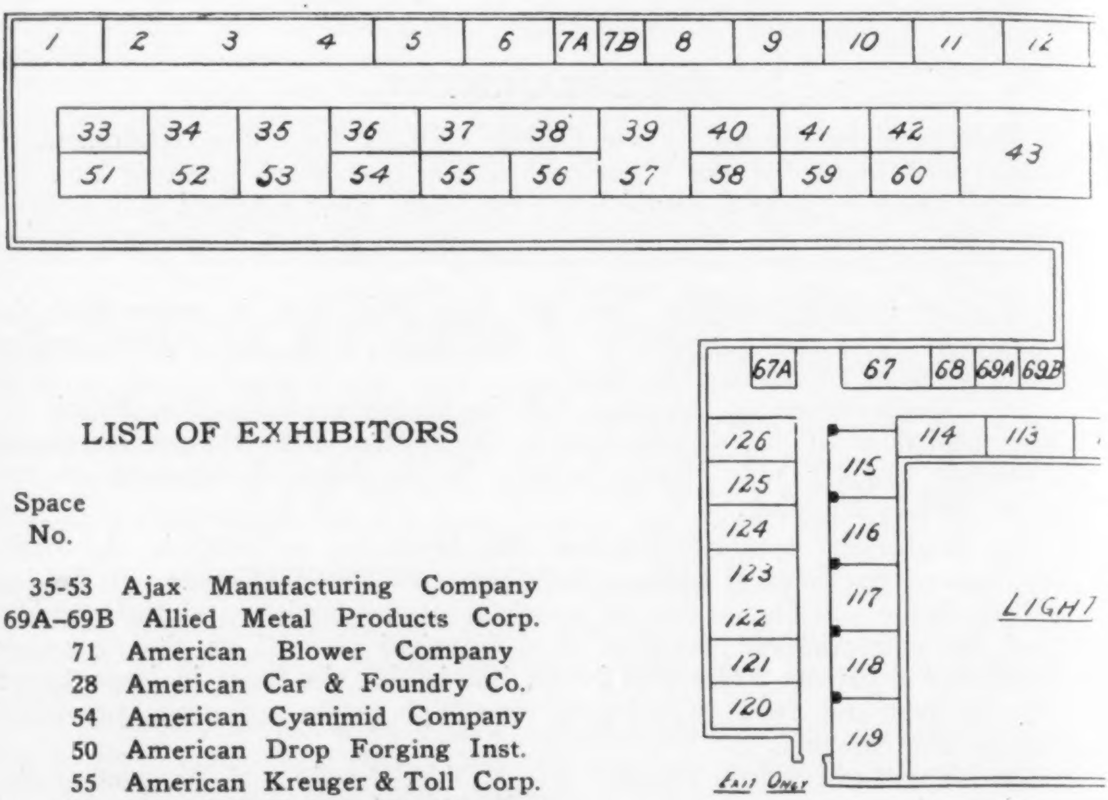
There have always been in the neighborhood of 100 visiting ladies present and inasmuch as the ladies of the American Drop Forging Institute are also to be entertained simultaneously with those of the American Society for Steel Treating, it is expected that at least 200 will be at the Detroit party during the week of October 2nd.

While no definite program is at present available, nevertheless, Mr. W. J. Learmouth, Studebaker Corporation, Chairman of the Ladies Entertainment Committee, has completed arrangements for a continual round of entertainment, sight seeing and auto trips for the guests.

The ladies will of course attend the Carnival, Frolic and Dance to be held at the General Motors Building on Wednesday, October 4, as well as attend the banquet at the Statler on Thursday evening. It has always been the motto of the American Society for Steel Treating for their members to bring their families and lady friends along and check them with the Entertainment Committee, and the same favorably received policy will be in vogue during the Detroit Convention.

(*Continued on page* 1080)

FLOOR PLAN AND LIST OF EXHIBITORS GENERAL MOTORS BUILDING

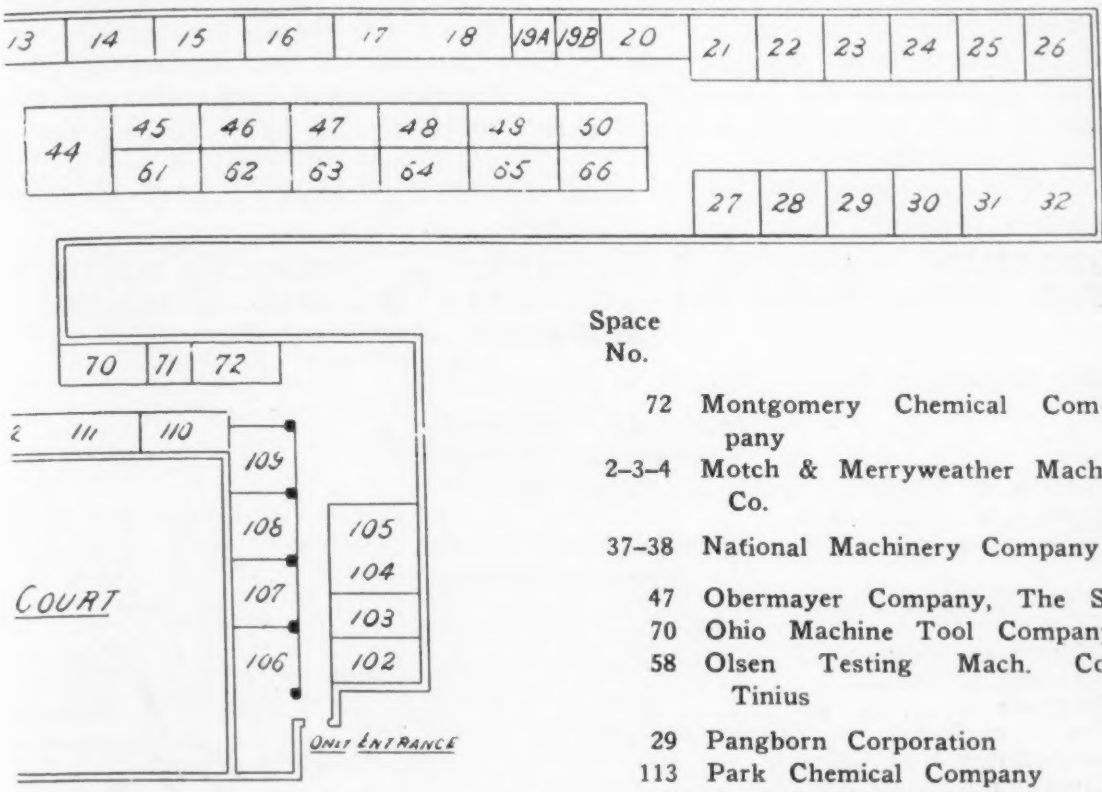


LIST OF EXHIBITORS

Space No.	
35-53	Ajax Manufacturing Company
69A–69B	Allied Metal Products Corp.
71	American Blower Company
28	American Car & Foundry Co.
54	American Cyanimid Company
50	American Drop Forging Inst.
55	American Kreuger & Toll Corp.
67A	American Refractories Co.
114	American Twist Drill Company
30	Armstrong-Blum Mfg. Co.
42	Armstrong Cork & Insul. Co
41	Atlas Steel Corporation
10	Bausch & Lomb Optical Co.
21	Bellevue Industrial Furn. Co.
106	Bethlehem Steel Company
125	Blaich Company, The A. O.
12	Bristol Company
61	Brown Instrument Company
117	Bureau of Standards
66	Calorizing Co. of Pittsburgh
23	Carborundum Company
14	Case Hardening Service Co.
48	Celite Products Company
111–112	Central Steel Company
25	Chicago Flexible Shaft Co.
43	Climax Molybdenum Company
16	Colonial Steel Company
68	Combustion Utilities Corp.
34	Crucible Steel Co. of America
108	Dearborn Chemical Company

Space No.	
1	Driver-Harris Company
27	Electric Furnace Company
26	Electro-Alloys Company
8	Engelhard, Inc. Chas.
43	Finkl & Sons, A.
104–105	Firth-Sterling Steel Company
7a	Ford Company, The J. B.
64	Forging & Heat Treating
9	Ganschow Company, Wm.
7B	Goddard & Goddard Co. Inc.
44	General Alloys Company
31-32	General Electric Company
13	Hagan Company, The Geo. J.
52	Halcomb Steel Company
118	Hauck Manufacturing Company
56	Haynes-Stellite Company

INTERNATIONAL STEEL EXPOSITION
DETROIT, MICHIGAN



Space No.	
11	Heppenstall Forge & Knife Co.
49	Holcroft & Company
63	Hoskins Manufacturing Co.
33	Houghton & Company, E. F.
115	International Nickel Co.
40	Interstate Iron & Steel Co.
15	Iron Age
5	Keller Mechanical Engrav. Co.
116	Keystone Refractories
67	King Refractories Co.
19a	Kleist & Company, Chas.
39–57	Leeds & Northrup Company
45	Leitz, Inc. E.
193	Machinery
6	Midvale Steel & Ordnance Co.
55	Midwest Steel & Supply Co.

Space No.	
72	Montgomery Chemical Company
2–3–4	Motch & Merryweather Mach. Co.
37–38	National Machinery Company
47	Obermayer Company, The S.
70	Ohio Machine Tool Company
58	Olsen Testing Mach. Co. Tinius
29	Pangborn Corporation
113	Park Chemical Company
65	Penn Seaboard Steel Corp.
109	Quigley Furnace Specialties Co.
62	Rockwell Company, The W. S.
36	Rodman Chemical Company
126	Shore Instrument & Mfg. Co.
51	Simonds Manufacturing Co.
20	Spencer-Turbine Company
124	Standard Alloys Company
24	Standard Fuel & Engr. Co.
102	Standard Steel & Bearings, Inc.
22	Surface Combustion Company
110	Taylor Instrument Company
60	Taylor Company, The N. & G.
122–123	United Alloy Steel Company
107	Vanadium Alloys Steel Company
103	Vanadium Corporation of Am.
17–18	Westinghouse Elec. & Mfg. Co.
46	Wilson-Maeulen Company
59	Witherow Steel Company

(*Continued from page* 1077)

DROP FORGE SUPPLY ASSOCIATION

Mr. H. N. Taylor, President of the N. & G. Taylor Company and President for the past eight years of the Drop Forge Supply Association, has made arrangements for the holding of a meeting of the members of the association during the International Steel Exposition and Conventions of the American Society for Steel Treating and the American Drop Forging Institute in Detroit.

The meeting will be held at 12:30 on Tuesday, October 3, in the General Motors Building.

PROGRAM — ANNUAL CONVENTION — AMERICAN SOCIETY FOR STEEL TREATING —GENERAL MOTORS BUILDING— DETROIT

The following program is subject to change.

MONDAY, OCTOBER 2

Morning Session

11:00 A. M. Exposition open until 10:00 P. M.
11:00 A. M. Registration.
All technical sessions held in General Motors Building.

Afternoon Session

2:00 P.M. Plant Visitation.
L. A. Danse, Chairman.
Address of Welcome........L. A. Danse
Welcome to Detroit........Mayor Cousins
Response........Pres. F. P. Gilligan
Report of Tellers of Election........C. G. Shontz
Introduction New Officers.
Report of National Secretary........W. H. Eisenman
Report of Treasurer........J. V. Emmons
Report of National Committees.
President's Address........F. P. Gilligan

TUESDAY, OCTOBER 3

Morning Session

10:00 A. M. Exposition open until 10:00 P. M.
10:00 A. M. Plant Visitation.
10:00 A. M. Carburizing Session.
Carburizing and Decarburizing in Case Hardening........H. B. Knowlton
Case Handening........A. H. d'Arcambal
Irregularities in Case Hardened Work Caused by Improperly Made Steel ....E. W. Ehn
Some Features of Industrial Heat Treating Electrically........C. L. Ipsen

Afternoon Session

2:00 P. M. Plant Visitation.
2:00 P. M. Delegate Session.
Chairman, T. D. Lynch.
Vice Chairman, A. W. F. Greene.
2:00 P. M. The Mining and Metallurgy of Nickel—Illustrated.......A. J. Wadhams
4:00 P. M. Symposium on Metallurgical Education.
"Not How but What to Teach".
Prof. S. L. Goodale, University of Pittsburgh, Chairman.
4:00 P. M. Practical Round Table Discussion on Heat Treating.
H. J. Lawson, Chairman.
9:30 P. M. Smoker and Entertainment.
Auditorium—General Motors Building.

WEDNESDAY, OCTOBER 4

Morning Session

10:00 A. M. Exposition open until 10:00 P. M.

10:00 A. M. Plant Visitation.
10:00 A. M. General Heat Treating Problems.
Heat Treating in Lead ....R. B. Schenck
Furnace Atmospheres and Their Relation to Formation of Scale.
....G. C. McCormick
Paper ....J. H. Nelson
Thermal Transformation of Some Chrome Vandium Steels.........J. S. Vanick
Heat Treating of Auto Springs................................A. E. Fuller

Afternoon Session

2:00 P. M. Plant Visitation.
2:00 P. M. Drop Forge Institute Session.

Papers

The papers during this session will be presented by the American Drop Forging Institute and will be of great interest and practical value to the executives of all industrial organizations.
4:00 P. M. Practical Round Table Discussion on Heat Treating.
Chairman, John Halbing.
9:00 P. M. Carnival, Frolic and Dance.
Auditorium—General Motors Building.

THURSDAY, OCTOBER 5

Morning Session

10:00 A. M. Exposition open until 5:30 P. M.
10:00 A. M. Plant Visitation
10:00 A.M. Tool Steel Session.
The Uses and Abuses of Tool Steels from the Standpoint of the Producer and Consumer ....W. P. Woodside
Paper ....A. E. White
Effects of Structure upon Machining of Tool Steel...............J. V. Emmons
A Metallographic Study of Hollow Drill Steel...................N. B. Hoffman

Afternoon Session

2:00 P.M. Plant Visitation.
2:00 P. M.
Some Failures in Aircraft Plane and Engine Parts...............J. B. Johnson
Lathe Breakdown Tests of Some Modern High Speed Tool Steels.
....H. J. French and Jerome Strauss
Paper ....F. M. Nair
Deterioration of Steel and Wrought Iron in Hot Gaseous Ammonia. J. S. Vanick
4:00 P. M. Practical Round Table Discussion on Heat Treating Problems.
Robt. Vincent, Chairman.
7:00 P. M. Annual Banquet—American Society for Steel Treating and American Drop Forging Institute.
Ball Room—Statler Hotel.
Doors open 6:30 P. M.

FRIDAY, OCTOBER 6

Morning Session

10:00 A. M. Exposition open until 10:00 P. M.
10:00 A. M. Plant Visitation.
10:00 A. M.
Heat Treatment and Properties of Duralumin....................H. C. Kneer
10:45 A. M. Meeting of Standards Committee of American Society for Steel Treating.
T. D. Lynch, Chairman
10:45 A. M. Modern Methods in the Manufacture of Steel.
Moving Pictures.

Afternoon Session

2:00 P.M. Plant Visitation.
2:00 P. M. Research Session.
A. E. White, Chairman.
Governmental Research ....W. M. Corse
Research on Activities of Technical Societies.....................A. D. Flinn
The Research Laboratory......................................F. O. Clements
The Executive and Research...................................John A. Mathews

LIST OF EXHIBITORS AND WHAT THEY WILL EXHIBIT AT INTERNATIONAL STEEL EXPOSITION, GENERAL MOTORS BUILDING, DETROIT, OCTOBER 2-7

Ajax Manufacturing Company, Cleveland. Spaces 35-53, will exhibit:
Working Model Twin Geared Upsetting Forging Machine, length overall about 30 inches, made principally from aluminum.
Working Model, motor-driven direct gear connected Board Drop Hammer about 30 inches high, made principally from aluminum.
Display of interesting sample forgings, all made by Ajax Machine methods.
In charge of booth: J. R. Blakeslee, President; W. W. Criley, R. A. Bannerman, H. D. Heman, all from Cleveland office. J. A. Murray, Manager, New York office; A. L. Guilford, Manager, Chicago office.

Allied Metal Products Corporation, Detroit. Space 69, will exhibit:
Nickel Alloys. Heat resisting—non-corrosive, in sheets, bars and castings and finished product.
In charge of booth: V. Hybinette, W. J. Moore.

American Blower Company, Detroit, Mich. Space 71, will exhibit:
Man Cooling Fan—operates as a very large desk fan directing a cooling breeze over workmen employed before furnaces or other hot machines.
Pressure Blower—for furnishing blast for furnaces.
Utility Blower—for blowing scale from forging dies.
Domestic Kitchen Ventilating Unit—something new to take the odors, steam and fumes from the kitchen, an article of general interest.
In charge of booth: G. C. Polk, Manager, Standard Apparatus Division; J. B. Dill, Manager, Detroit sales office; O. F. Polk, Manager, Standard Apparatus Division; W. A. Rane, Chief Engineer.

American Car & Foundry Company, New York City. Space 28, will exhibit:
One No. 3 Three Electrode Berwick Electric Rivet Heater for heating rivets or short pieces of steel electrically.
One No. 3 One Electrode Type E Berwick Two Path End Rod or Forging Heater for heating one end of a rod of any diameter from ¼-inch to 1-inch, giving any desired length of heat from 1-inch to 8 inches, or longer if desired.
One No. 3 Four Foot Berwick Electric Rod Heater, for heating any diameter rod up to 1 inch, for hand feet rivet and bolt machine and for long heats in forging operations.
In charge of booth: J. M. Hayes, A. G. Wood, A. F. Frost, F. C. Cheston.

American Cyanamid Company, New York City. Space 54, will exhibit:
Cyanide Products for Heat Treating Steel.
In charge of booth: E. J. Pranke.

American Drop Forging Institute, Cleveland. Space 50, will exhibit:
Typical Drop Forgings supplied by executive members of Institute.
In charge of booth: R. E. Waldron, Dominion Forge & Stamping Co., Walkerville, Ontario, Canada.

American Kreuger & Toll Corporation, New York City. Space 55, will exhibit:
Air Filters; transmission steel sections, timber joint plate.
Nitrol—a new hardening process.
In charge of booth: Dr. F. Rohde.

American Twist Drill & Tool Company, Detroit. Space 114, will exhibit:
High Speed Drills and Cutting Tools.
In charge of booth: L. C. Gonham, C. G. Munn, F. E. Henderson.

Armstrong-Blum Mfg. Company, Chicago. Space 30, will exhibit:
"Marvel" Automotive High Speed Hack Saw Machine.
"Marvel" Metal Band Saw.
"Marvel" Punch, Shear and Bender.
In charge of booth: H. J. Blum, Secretary, Chicago; G. J. Blum, Vice President, Chicago.

Armstrong Cork & Insulation Company, Pittsburgh. Space 42, will exhibit:

Nonpareil Insulating Brick for insulation of furnaces, ovens, boiler settings, kilns, retorts, etc.
Nonpareil High Pressure Covering, blocks and cement for insulation of steam lines, boilers and other high temperature equipment.
Nonpareil Cork Covering for insulation of refrigerated drinking water, brine and ammonia lines, coolers, tanks, etc.
Nonpareil Corkboard Insulation for insulaton of cold storage and constant temperature rooms, tanks, etc.
Linotile and Armstrong's Cork Tile for floors.
In charge of booth: S. L. Barnes, Advertising Department; W. C. Rasch and E. D. Summers, of Detroit office.

Atlas Steel Corporation, Dunkirk and Charleroi, Pa. Space 41, will exhibit:

Full line of tool and high speed steels; also samples and fractures of same in various metallurgical conditions.
Full line of special steels, such as magnet, valve, non-corrosive and ball-bearing steels.
Description of alloy steels manufactured and their applications.
In charge of booth: W. C. Peterson, M. Grossmann, Frank Lounsbury, Wm. H. Wills.

Bausch & Lomb Optical Company, Rochester, N. Y. Space 10, will exhibit:

Complete line of metallurgical microscopes and metallographic equipment, ranging from simplest types, suitable for general foundry use, to most complete equipments for research laboratory work.
New Contour Measuring Projector, by means of which contour of screw threads, gear cutting tools and small machine parts may be accurately and rapidly checked. This equipment should be of much interest to the Steel Treater, as it will be the means of definitely settling the question of distortion, due to heat treatment.
These equipments will be in actual operation, and our representatives will welcome the opportunity of conferring with those interested in installation of equipment or those already having equipment upon which additional information may be desired.
In charge of booth: W. L. Patterson, I. L. Nixon.

Bellevue Industrial Furnace Company, Detroit, Mich. Space 21, will exhibit:

One High Speed Furnace with casing cut away to show interior construction.
A duplicate of above furnace under actual operation.
Pyrometer equipment in connection with above to be supplied by Brown Instrument Company.
In charge of booth: P. P. Barker, Walter Hinz, L. J. Raymo, C. Voelker, Erich Hinz.

Bethlehem Steel Company, Bethlehem, Pa. Space 106, will exhibit:

Castings made with Mayari Pig Iron—A pig iron made from ores containing nickel and chromium naturally and used for automobile cylinders, pistons and other special iron castings.
Bethlehem Rolled Steel Wheels.
In charge of booth: T. J. Fitzgibbons, Sales Agent—Drop Forgings. W. C. Cutler, Sales Agent—Bars and Billets. Robt. MacDonald—Foundry Specialist. P. Kruelen—Foundry Specialist. F. A. Wallen, Sales Agent—Bethlehem Rolled Steel Wheels. W. R. Shimer, Sales Metallurgist.

Alfred O. Blaich Company, Detroit, Mich. Space 125, will exhibit:

Carbonizing Materials.
"Quick Case"—for cyaniding purposes.
"Quick Heat"—for heat treating purposes.
INSULITE—for selective hardening.
Leadcoat—for covering lead bath.
Specimens treated with Blaich Products.
In charge of booth: Frederick Pugh, 555 Beaufait Ave., Detroit; J. A. Howland, 555 Beaufait Ave., Detroit; S. W. Baldwin, 555 Beaufait Ave., Detroit.

Bristol Company, Waterbury, Conn. Space 12, will exhibit:

Bristol's Recording Indicating Electric Pyrometers, Controllers, etc.
In charge of booth: H. L. Griggs.

Brown Instrument Company, Philadelphia. Space 61, will exhibit:

Low and High Temperature Automatic Control.
Indicating and Recording Pyrometers, Recording Thermometers, Pressure Gauges, etc.
In charge of booth: Geo. W. Keller.

British American Nickel Corporated, Ltd. Space 69, will exhibit:

Nickel in ingot.
Cathode and shot form.
In charge of booth: L. J. Buck.

Bureau of Standards, Washington, D. C. Space 117, will exhibit:

General equipment available for research and testing of metals at the Bureau of Standards will be shown by photographs and transparencies and copies of publications considered of interest to the members of the two societies will be available for examination.

A recording chronograph for direct plotting of inverse rate heating and cooling curves, which was recently constructed at the Bureau, will be in operation.

Production of pure metals such as iron and preparation of gas free alloys, together with melting of different industrial ferrous and non-ferrous metals by various methods, will likewise be illustrated.

In connection with this work, methods developed for determination of gases in metals will be shown. Such investigations, which have been pursued intensively for several years at the Bureau of Standards, are fundamental and their perfection must necessarily be achieved before the effects of various gases contained in alloys, such as steels, manufactured by various processes may be determined.

Hot and cold working of metals, their heat treatment and testing including some applications of the 2,300,000-lb. Emery testing machine will be shown. There will also be included the results of recent studies of the properties of ferrous and non-ferrous metals at high temperatures and a model car wheel, showing a method of study of the distribution of stresses under conditions approximating those of service.

A set of gages finished by the Hoke method and typical standard samples prepared by the Bureau will be at hand.

The material available will illustrate the field of co-operation of the Bureau with the metal industries.

In charge of booth: G. K. Burgess, H. J. French, J. S. Vanick, T. G. Digges, Miss D. E. Kingsbury.

Calorizing Company of Pittsburgh. Space 66, will exhibit:

Calorized Recuperator Tubes; Calorized Pyrometer Protection Tubes; Calorized Annealing and Carburizing Tubes and Calorized Burners.

Calite Roller for continuous furnaces; Calite furnace skids; Calite pots and boxes.

Photographs of installations of Calorizing and Calite.

In charge of booth: B. L. Jarrett, President; A. V. Farr, Vice President, and Sales Manager; E. L. Malone, F. D. Rice.

Carborundum Company, Niagara Falls. Space 23, will exhibit:

Refractory Materials.
Abrasive Materials.
In charge of booth: W. W. Sanderson, C. E. Hawke.

Case Hardening Service Company, Cleveland, Ohio. Space 14, will exhibit:

Case Hardening Compound and Hardening Room Supplies.
Samples of:
Bohnite for Pack Hardening.
Caseite for Cyanide Hardening.

Samples of work produced by representative manufacturers using our materials.
In charge of booth: E. J. Gossett, C. E. Lovejoy, W. C. Bell, C. E. Pullum, J. L. Stroman, Wm. H. Bell

Celite Products Company, Chicago. Space 48, will exhibit:
Small electric furnace, one side of which is constructed of ordinary fire brick and other of Sil-O-Cel Insulating Brick. Thermometer attached to the exterior of each side to show how easily heat penetrated fire brick and resistance to heat flow of Sil-O-Cel Insulation.
Complete display of all Sil-O-Cel Insulating products as well as Filter-Cel for filtration and Celite Mineral Filler.
In charge of booth: C. L. Burnham, Chicago; A. B. Rogers, Detroit.

Central Steel Company, Massillon, Ohio. Spaces 111-112, will exhibit:
Alloy Steels—Various finished products made from alloy steels.
Steel Sheets—High-finish automobile sheets.
Strip Steel—Hot Rolled Alloy Steel and Hot Rolled Carbon Steel.
Physical charts, microphotographs.
In charge of booth: F. J. Griffiths, Vice President and General Manager; J. M. Schlendorf, Director of Sales; Gilbert Canterbury, Manager Sales Promotion; Earl Smith, Chief Metallurgical Engineer; C. P. Richter, Metallurgical Engineer; Arthur Schaeffer, Manager Detroit Sales Office.

Chicago Flexible Shaft Co., Chicago. Space No. 25, will exhibit:
Furnaces in operation, controlled by the Selas System.
In charge of booth: Peter Blackwood.

Climax Molybdenum Company, New York City. Space 43, will exhibit:
Products made from Molybdenum Steel.
In charge of booth: John D. Cutter.

Colonial Steel Company, Pittsburgh, Pa. Space 16, will exhibit:
Material used in the Manufacturing of Colonial Tool Steels.
In charge of booth: N. B. Hoffman, Metallurgist; J. Trautman, Jr., Assistant General Sales Manager; G. W. Hampshire, Manager Detroit Branch; C. O. Sternagle, Manager Chicago Branch; F. L. Stevenson, Manager Cleveland Branch; Colin McInnis, Special Sales Agent; Chas. Kopenhoefer, Special Sales Agent; Jesse M. Smith, Special Sales Agent; J. E. Barry, Special Sales Agent.

Combustion Utilities Corporation, New York City. Space 68, will exhibit:
Lead and Oil Tempering Bath.
Muffle Furnace Rivet Forge.
Recuperator Sections.
Drawings for Recuperative and Regenerative Furnaces.
Wooden Models of Recuperative Forge Furnace and Recuperative Heat Treating Furnace.
In charge of booth: G. L. Ballard, 915 Park Avenue, Beloit, Wisconsin; P. J. Nutting, 327 S. Erie Street, Toledo, Ohio; H. M. Henry, 327 S. Erie Street, Toledo, Ohio.

Crucible Steel Co. of America, New York City. Space 34, will exhibit:
High Speed, Carbon and Alloy Tool Steels.
Hot Rolled, Cold Rolled and Cold Drawn Shapes.
Non-Changeable, Non-Corrosive, Acid and Rust Resisting Steels.
Alloy Machinery Steels of all varieties and for every purpose.
In charge of booth: Dr. John A. Mathews, President; R. Michener, General Sales Agent; C. M. Johnson, Director Research Department; A. L. Ralston, Manager Detroit Branch; J. W. Taylor, F. J. White and other representatives of Sales, Operating and Service departments.

Dearborn Chemical Company, Chicago. Space 108, will exhibit:
No-Ox-Id, The Original Chemical Compound Rust Preventive in various consistencies and methods of application.
Quenching Oils.
Cutting Oils.
Cleaners, Powdered and Liquid, known as Klean Kleen and Dearboline.
In charge of booth: E. M. Converse, Director Department of Specialties, Dear-

born Chemical Company, Chicago, Illinois; O. L. Fleugel, Detroit; C. I. Loudenback, Detroit; E. H. Ruhlman, Cleveland; C. A. Remsen, Washington; T. H. Platt, New York.

Driver-Harris Company, Harrison, N. J. Space 1, will exhibit:
Nichrome Castings.
In charge of booth: W. E. Blythe, Driver-Harris Company, Detroit, Michigan; L. Edwards, Canadian Driver-Harris Co., Ltd., Walkerville, Ontario, Canada; H. O. Hartdegen, Driver-Harris Company, Detroit, Mich.; H. D. McKinney, Driver-Harris Company, Chicago, Ill.; G. A. Rickert, Driver-Harris Company, Harrison, N. J.

Electric Furnace Company, Salem, Ohio. Space 27, will exhibit:
Typical products which are being produced in electric furnaces for heating, heat-treating, annealing and enameling in this country.
Exhibit will show wide range of application of electric heat for these purposes.
Products will range from anchor chain, draw bar knuckles and locomotive axles, down to bolts, ball races and small steel parts.
Also model furnace units to show latest designs in electric furnace for metallurgical problems.
In charge of booth: T. F. Baily, Vice President; R. F. Bensinger, Sales Manager; F. J. Peterson, Detroit Representative; R. F. Fletcher, Advertising Manager; M. T. Ellis, Salesman.

Electro-Alloys Company, Elvria, Ohio. Space 26, will exhibit:
Thermalloy castings showing products and various uses.
Difficult castings.
In charge of booth: Heman Ely, Jr.

Chas. Engelhard, Inc., New York City. Space 8, will exhibit:
Complete line of temperature measuring instruments in operation, including both indicating and recording Le Chatelier Pyrometers and recording electric resistance thermometers.
Automatic control apparatus applicable to electric, gas or oil fired furnaces will be shown and controls on electric and gas fired furnaces will be in operation.
Many different forms of thermo-couple mountings.
Impervite pyrometer tubes and chemical ware will be displayed and interesting demonstrations made of the imperviousness of this ware and its resistance to sudden temperature changes.
In charge of booth: E. S. Newcomb, J. H. Oetjen, H. L. Shippy.

A. Finkl & Son, Chicago. Space 43, will exhibit:
Molybdenum Die Blocks.
In charge of booth: William Finkl.

Firth-Sterling Steel Company, McKeesport, Pa. Spaces 104-105, will exhibit:
Blue Chip High Speed Steel.
Firth-Sterling Special Tool and Die Steel.
Firth-Sterling (S-LESS) Steel, which is proof against ordinary agencies of rust, stain and corrosion.
In charge of booth: E. T. Jackman, G. A. Jacobs, W. C. Royce, W. A. Nungester, I. Olsen, T. A. Larecy

J. B. Ford Company, Wyandotte, Michigan. Space 7, will exhibit:
Methods of agitating solutions with air.
Wyandotte Cleaning Specialties.
In charge of booth: B. N. Goodell.

Forging & Heat Treating, Pittsburgh. Space 64, will exhibit:
Publications.
In charge of booth: E. C. Cook, Mr. Yeager, Geo. Grant.

William Ganschow Company, Chicago. Space 9, will exhibit:
William Ganschow Company Type A, B and C Speed Transformers,
Direct Connected—Type A.
Right Angle Drive—Type B.

Vertical Drive—Type C.
Automobile Transmission Gears.
Spiral Bevel Drive and Differental Gears.
Noiseless Bakelite Timing and Rawhide Gears—for the Commercial Trade. mercial Trade.
Spur Gears for 1-inch Outside Diameter to 12 Feet Diameter 20-inch Face.
Bevel and Mitre Gears.
In charge of booth: F. J. Niedermiller, Detroit representative, 4835 Woodward Avenue, Detroit, Michigan.

General Alloys Company, Chicago. Space 44, will exhibit:
Q-Alloys.
Wireless Bulletins—all apparatus in booth.
In charge of booth: H. H. Harris, A. L. Grinnell.

General Electric Company, Schenectady, N. Y. Spaces 31-32, will exhibit:
Electrical Heating Apparatus for Steel Treating.
In charge of booth: C. L. Ipsen, H. Fulwider, C. T. McLaughlin.

Goddard & Goddard Company, Detroit, Mich. Space 7B, will exhibit:
Their line of special "Go and Go" Milling Cutters as adapted for various lines of milling, special attention being paid to cutters for railroad work, automobile work and general purpose milling.
In charge of booth: A. N. Goddard, President; C. S. Goddard, Sales Manager; R. T. Rice, Ohio Representative.

Geo. J. Hagan Company, Pittsburgh. Space 13, will exhibit:
Photographs of a number of installations of electric, coal fired and oil and gas fired equipments.
Complete operating results, also blueprints and specifications will be available.
Bulletins describing the several types of furnaces will be distributed.
In charge of booth: J. Sandberg, Manager Detroit Office; R. E. Talley, Chief Engineer; E. F. Cone, A. D. Dauch.

Halcomb Steel Company, Syracuse. Space 52, will exhibit:
Tool and Alloy Steels and products made therefrom.
In charge of booth: H. J. Stagg, Sam Spalding.

Houck Mfg. Co., Brooklyn. Space 118, will exhibit:
Burners and rivet furnaces.
In charge of booth: C. J. Schwenk.

Haynes Stellite Company, New York City. Space 56, will exhibit:
Rounds, squares and flats of Stellite bar stock.
Stellite welded tip tools.
Numerous special castings, which have been successfully applied as valves, dies, etc.
Automatic device for removing of surface flaws from "Hot steel billets." Stellite is used as the scraper and is the only metal known that will stand up under the terrific heat and abrasion encountered.
Stellite milling cutters of various types.
Stellite tipped lathe centers.
Special knives used for cloth cutting, rubber cutting, linoleum cutting, etc.
Assortment of drawing dies, extrusion dies, ring dies, etc.
In charge of booth: F. J. Frank, C. S. Baur, W. B. Robinson, D. C. Warren.

Heppenstall Forge & Knife Company, Pittsburgh. Space 11, will exhibit:
One Hammer Ram, machined complete.
Two Hammer Guides, rough machined.
One Sow Block, rough machined.
One Solid Head Piston Rod, rough machined.
One Annealed Die Block, in the condition in which it is shipped.
One Treated Die Block, in same condition.
One Hardtem Die Block, in same condition.
One Hardtem Die Block, cut in half and polished to show the effects of heat treatment.
One shear knife for shearing rounds, such as are used in a drop forge shop.
One shear knife for shearing shapes.

One enlarged photograph of 7000-lb. steam hammer installed in 1892 by Trethewey Manufacturing Co., predecessors of Heppenstall Forge & Knife Company.
Various difficult drop forgings which have been made from different grades of our die blocks.
In charge of booth: E. H. Graham, Detroit District; J. J. Cruice, Detroit District; A. L. Wurster, Philadelphia District; G. I. Allen, Cleveland District; C. W. Heppenstall, Treasurer and General Manager; Floyd Rose, Secretary and General Sales Manager.

Holcroft & Company, Detroit. Space 49, will exhibit:
Photographs; miniature designs for heating elements and furnaces; complete designs and drawings of electric furnaces and quench devices; also general information on all types of furnaces and ovens.
Also daily visits to plants where firm has electric furnaces in operation. These will be conducted personally by a representative of the company.
In charge of booth: F. J. Frank, C. S. Baur, W. B. Robinson, D. C. Warren, Treasurer; H. L. Ritts, Sales Manager; C. L. Joy, Chief Engineer.

Hoskins Manufacturing Company, Detroit. Space 63, will exhibit:
Pyrometers and Electric Heat Treating Furnaces.
Features will be a furnace with a new type of heating element, and automatically controlled by a new type of temperature regulator.
In charge of booth: C. S. Kinnison, W. A. Gatward, R. P. Ellis, J. D. Sterling, J. W. Moore, A. S. Lee.

E. F. Houghton & Company, Philadelphia. Space 33, will exhibit:
Oils, leathers and carburizing materials.
In charge of booth: Louis E. Murphy, George W. Pressell, C. W. Cressman.

International Nickel Company, New York City. Space 115, will exhibit:
Nickel and Nickel Products.
In charge of booth: Dr. Paul D. Merica, A. J. Wadhams, A. E. Turner.

Interstate Iron & Steel Company, Chicago. Space 40, will exhibit:
Various important parts of automobiles of different makes made from Interstate Alloy Steels.
In charge of booth: E. Larned, 104 S. Michigan Avenue, Chicago; W. J. MacKenzie, 104 S. Michigan Avenue, Chicago; Paul Llewellyn, 104 S. Michigan Avenue, Chicago; F. W. Guibert, Ford Building, Detroit; H. L. Couzens, Ford Building, Detroit; R. S. LeBarre, 104 S. Michigan Avenue, Chicago.

Iron Age, New York City. Space 15, will exhibit:
The Iron Age.
In charge of booth: F. J. Frank, C. S. Burr, W. B. Robinson, D. C. Warren, H. E. Barr, B. L. Herman, C. Lundberg, E. Findley, F. S. Wayne, D. G. Gardner, C. L. Rice, E. Sinnock, F. Schultz, W. C. Sweetser, A. L. Marsh, O. B. Bergersen, W. W. Macon, E. S. Cone, G. L. Lacher, S. L. Prentiss, R. E. Miller.

Keller Mechanical Engraving Company, Brooklyn. Space 5, will exhibit:
In operation, the New Type "F" Automatic Die Sinking Machine embodying striking revolutionary features; entirely electrically driven; push button controls for every movement; follows any contour, besides feeding horizontally or vertically; operation, Automatic, Semi-Automatic or by Hand. Original wood or plaster patterns can be used as masters. Heavy cutting with big mills.
In charge of booth: Jules Dierckx, S. A. Keller, Charles Bitter, A. J. Benson.

Keystone Refractories Company, New York City. Space 116, will exhibit:
Dura-Stix—the high temperature cement.
Crundumsand—a dense high refractory granular material.
These articles are used as refractories for furnace economy.
In charge of booth: F. W. Reisman, President; L. E. Turk, Treasurer; G. M. Sherman, New England Sales Manager; H. A. O'Brien, S. W. Cole, local representatives.

Charles Kleist & Son, Jamestown, N. Y. Space 19A, will exhibit:
Drop Hammer Boards for Board Drop Forge Hammers.
(a) Built-Up-Board—(New Principle).
(b) Cut-in-Board.
(c) Standard Board.

In charge of booth: H. Brewer, C. A. Martin, A. F. Moranty, G. W. Tall, Jr.,

Leeds & Northrup Company, Philadelphia. Spaces 39-57, will exhibit:

Potentiometer Pyrometers for indicating, recording, or signaling temperatures, or for the complete automatic control of temperatures.

Equipment for heat treating according to the Hump Method, both tool type and production type equipments.

Equipments will be in operation and actual hardening performed at the show.

In charge of booth: H. Brewer, C. A. Martin, A. F. Moranty, G. W. Tall, Jr., A. E. Tarr, Jordan Korp.

E. Leitz, Inc., New York City. Space 45, will exhibit:

The Well-known Leitz "*Micro-Metallograph*" in conjunction with the new Vibration Absorber, which solved a problem every Metallurgist had to combat with.

General Metallurgical Microscope Equipments with a full line of "*Apochromatic*" Objectives and "*Periplan*" Eyepieces.

Grinding and Polishing Machines for the preparation of microscopical specimens.

In charge of booth: G. Sauppe.

Machinery, New York City. Space 19B, will exhibit:

Machinery and its publications.

In charge of booth: J. N. Wheeler.

Midvale Steel & Ordnance Company, Philadelphia. Space 6, will exhibit:

Booth will be used primarily for reception purposes.

Special decorative features will advertise our complete line of carbon, alloy and high speed tool steels, etc.

In charge of booth: S. Hazlewood, Manager Forging Division; H. E. Rowe, in charge of Tool Steel Sales; R. E. Dexter, Manager Detroit District Office; G. A. Richardson, in charge of Advertising and exhibits, etc.

Midwest Steel & Supply Co., Inc., New York City. Space 55, will exhibit:

Midwest Unit Air Filters.
Midwest Compressor Type Filter.
Midwest Type "D" Filter.
Midwest Tractor Filter.
Midwest Steel Sections.
Midwest Inserts.
In charge of booth: A. M. Goodloe.

Montgomery Chemical Company, Detroit, Michigan. Space 72, will exhibit:

Their full line of Case Hardening Compound and method of manufacturing.

A miniature exhibit of part of our commercial heat treating department in Detroit.

In charge of booth: L. C. Dunn.

Motch & Merryweather Company, Cleveland. Spaces 2-3 and 4, will exhibit:

Complete line of Machinery in operation.

In charge of booth: Geo. Merryweather, Stanley Motch, Geo. Lawrence.

National Machinery Company, Tiffin, Ohio. Spaces 37-38, will exhibit.

Forging Machinery.

In charge of booth: E. F. Frost, F. J. Mawby, K. L. Ernst, F. W. Klenk, C. D. Harmon.

S. Obermayer Company, Chicago, Space 47 will exhibit:

Five grades of super refractories and high Temperature cements, showing their application in various types of furnaces, etc.

Various sizes and grades of charcoal, various sizes and grades of plumbago and graphite and various grades of refractories and shapes processed from refractories which we manufacture and various grades of polishing material, sand blast, sand, etc.

In charge of booth: J. L. Cummings; Mr. Geer, Detroit; Mr. Newman.

Ohio Machine Tool Company, Kenton, Ohio. Space 70 will exhibit:

Metal Working Shapers.

In charge of booth: C. C. Swift; R. D. Shields; Wm. Ochse; L. H. Peters; all of Kenton, Ohio.

Tinius Olsen Testing Machine Co., Philadelphia. Space 58 will exhibit:

Machines for applying impact tests; alternate stress tests, repeated impact tests, Brinell hardness test, special hardness tests for sheet metal both soft and hard.

Universal Testing Machines with various attachment for testing in tension, compression and transverse; ductility tests of sheet metal, hydrostatic tests; tests of welding material.

Special machines for determining ductility and drawing quality of sheet metal known as the Olsen Ductility Testing Machine.

Special equipment for testing welds and welding material known as the Owens Weld and Welding Material Equipment.

Various Extensometer, Strain Gauges and Instruments together with full data and details covering our Olsen-Carwen Static-Dynamic Balancing Machines for crankshafts, fly-wheels and other rotating parts, as used in the automobile and electrical world.

In charge of booth: R. B. Lewis, Engineering Department; T. Y. Olsen, Vice-President and Treasurer.

Pangborn Corporation, Hagerstown, Md. Space 29 will exhibit:

Cabinet Sand-Blast in operation.

Photographs of installations of various types of Sand-Blast.

Equipment in the Steel Treating Industry.

Various grades of Angular Steel Grit and Samson Steel Shot; dustless sand-blast abrasives in actual use in equipment demonstrating wearing qualities and finishes produced.

In charge of booth: John C. Pangborn, Vice President; H. D. Gates, Sales Manager; Chas. T. Bird, District Sales Engineer; W. C. Lytle, District Sales Engineer.

Park Chemical Company, Detroit, Michigan. Space 113 will exhibit:

Case Hardening Compounds for Carbonizing.

Cyanide Hardening Compounds for Cyanide Process.

Klean Heat for reheating bath.

Lead Pot Carbon for covering lead baths.

Quenching and Drawing Oils.

In charge of booth: D. W. Bauer; J. N. Bourg.

Penn Seaboard Steel Corporation, Philadelphia. Space 65 will exhibit:

Die Blocks; trimmer steel and heavy forgings.

In charge of booth: H. A. Baxter; D. J. Crowley.

Quigley Furnace Specialties Company, New York City. Space 109 will exhibit:

Hytempite—A plastic refractory material for bonding fire brick and other refractories. Its bonding qualities under severe temperature changes are demonstrated.

Carbosand—A highly refractory granular material for making rammed in linings, furnace bottoms, special tile, etc.

High Temperature Insulation—In brick, block, powder and cement form for retarding heat flow through furnace walls, ovens, and similar heated equipment.

In charge of booth: W. S. Quigley, President; W. H. Gaylord, Jr. Traveling Sales Manager; W. A. Toohill; H. M. Thompson.

W. S. Rockwell Company, New York City. Space 62 will exhibit:

Furnace models; catalogues; charts; photographs of installations.

In charge of booth: J. N. Voltman; C. D. Barnhart.

Rodman Chemical Company, Verona, Pa. Space 36 will exhibit:

"Carbo" Case Hardening Compounds.

"Sealright" Luting Material.

In charge of booth: Hugh Rodman, General Manager; G. A. Webb, Metallurgist, Detroit District Representative.

Shore Instrument & Mfg. Company, Jamaica, N. Y. Space 126 will exhibit:

Model C-1 Scleroscope Testing Set. Complete.

Model "D" Scleroscope Testing Set (Recording).

Pyroscope—Type "A".

Pyroscope—Type "B".

Durometer and Elastometer for plastic material as rubber, etc.

Local case—for selective carburizing.
Local hard—for selective hardness on tool steels.
Jigs and Fixtures for testing.
In charge of booth: F. G. Kendall, Hotel Griswold, Detroit, Michigan, Home address: Rosedale, N. Y.

Simonds Manufacturing Company, Lockport, N. Y. Space 51 will exhibit:
Steel bars and products; saws and knives.
In charge of booth: C. R. Paffenbach.

Spencer Turbine Company, Hartford, Conn. Space 20 will exhibit:
Spencer Turbo Compressors for supplying air for oil and gas burning industrial furnaces.
One Catalogue No. —, which will furnish air for all of the gas burning furnaces in operation and visitors will have opportunity to see machine operating under actual working conditions.
Smaller size machine, Catalogue, No. 1505.
Both of above machines are electric motor driven and form a complete integral unit.
In charge of booth: S. E. Phillips, Secretary; H. M. Grossman, Sales Manager; R. B. Richardson, Detroit Manager.

Standard Alloys Company, Pittsburgh, Pa. Space 124 will exhibit:
Ferro-vanadium
Ferro-uranium
Radium
In charge of booth: Hamilton Foley; D. H. Horne; H. A. Kraeling.

Standard Fuel Engineering Company, Detroit. Space 24 will exhibit:
Several types of tool hardening furnaces.
High Speed Furnace under heat.
Line of refractories including some very difficult shapes as well as high temperature cements.
In charge of booth: T. Q. Cleland; J. R. Dunne; E. B. Beeman; H. M. Bray.

Standard Steel & Bearings Incorporated, Philadelphia. Space 102 will exhibit:
Annular Ball Bearings—Single Row and New Style Double Row.
Steel Balls—Various stages of production.
Wire Wheels—Rudge-Whitworth.
In charge of booth: C. B. Wisenburgh, Western Sales Manager; B. H. Gilpin, Sales Engineer; L. A. Cummings, Chief Engineer; H. A. Johnston, Assistant to Sales Manager.

Surface Combustion Company, Chicago. Space 22 will exhibit:
Type-A-25 Gas Fired Oven Furnace for carbon or high speed steel hardening.
Volcano testing furnace for testing purposes at temperature up to 3400 degrees Fahr.—gas fired.
High pressure gas system showing operation of tunnel and impact type burners.
In charge of booth: W. M. Hepburn; A. L. Hollinger; S. R. Anderson.

Taylor Instrument Company, Rochester, N. Y. Space 110 will exhibit:
Electric Pyrometers—indicating and recording. Thermo Couples, Rotary Switches,
Signaling Pyrometers, Pyrometer Controls, Pyrometer Switchboards, Oil Tempering Bath Thermometers, Molten Metal Thermometers, Laboratory Thermometers, Mercury Actuated Recording Thermometers, Gas Actuated Recording Thermometers, Mercury Actuated Recording Thermometers, Gas Actuated Recording Thermometers, Mercury Index Thermometers.
In charge of booth: G. A. Howell, Rochester office; H. A. Hohes, Coon Devisser Company.

N. & G. Taylor Company, Philadelphia. Space 60 will exhibit:
Drop Forgings made from N. & G. Taylor Steels.
In charge of booth: H. N. Taylor, Geo. T. Allen, A. L. Wurster.

United Alloy Steel Corporation, Canton, Ohio. Space 122-123 will exhibit:
Various Steel samples subjected to several heat treatments and tests.
U'LOY steels made into: Bearings, Air Hammers; track tools; oil drilling tools;

shovels; special springs; locomotive forgings; foundry equipment; automotive parts.
In charge of booth: H. H. Pleasance, Sales Manager; W. H. Wiewel, Assistant Sales Manager; J. D. Jones, District Sales Agent; R. Wykoff; J. White; F. W. Krebs; R. E. Sherlock; F. B. Mulvaney; Earl Davidson.

Vanadium Alloys Steel Company, Latrobe, Pa. Space 107 will exhibit:
Board showing tools and parts manufactured from our various grades of Steel from the following:
Ward Tool & Forging Company, Latrobe, Pa.;
Service Tool Company, Newark, N. J.;
John Bath & Company, Worcester, Mass.;
Urbana Tool & Die Company, Urbana, Ohio;
Scott-Spencer, Cincinnati, Ohio;
A. Hankey & Company, Rochdale, Mass.;
Alemite Die Casting Co., Chicago, Ill.;
Spindles:
Heald Machine Company, Worcester, Mass.;
Norton Company, Worcester, Mass.
Hardened and Ground Rolls:
A. Hankey & Company, Rochdale, Mass.
Gripper Dies:
Severance Mfg. Company, Pittsburgh, Pa.
In charge of booth: J. P. Gill, Chief Metallurgist; A. F. MacFarland, Detroit Manager, D. D. Dodd, Detroit Office; A. R. Henry, Special representative; W. R. Mau, District Manager, Chicago Office, J. H. Caler, Cleveland Office; R. R. Artz, Pittsburgh Office.

Vanadium Corporation of America, New York City. Space 103 will exhibit:
Space will be used as a reception room.
In charge of booth: M. G. Baker, Vice President; G. L. Norris, Metallurgical Engineer, J. A. Miller, Jr. all located at Statler Hotel; W. R. Flannery, 849 Book Building, Detroit.

Westinghouse Electric & Manufacturing Company, Pittsburgh. Spaces 17-18 will exhibit:
Full line of electric furnaces and controls in full operation; oven and space heaters; electric solder pots; tempering ovens; and display of Krantz safety switches.
In charge of booth: C. C. Boos; A. D. Turner; W. S. Scott.

Wilson-Maeulen Company, New York City. Space 46 will exhibit:
Rockwell Direct Reading Hardness Testers.
Tapalog, Pyrometers Recorder.
Monopivot Pyrometers.
In charge of booth: C. E. Hellenberg; Harvey Lee; Harry Goldsen.

Witherow Steel Company, Pittsburgh, Pa. Space 59 will exhibit:
Various types of Forgings and Forging blanks with finished pieces.
Also exhibit entitled, "The Evolution of an Axle."
In charge of booth: W. P. Witherow, President; G. P. Norton, General Manager of Works; W. C. Emory, Metallurgist; L. A. Daines, Sales Engineer.

SYMPOSIUM ON HARDNESS TESTING

THE Committee on Hardness Testing of Metals, Division of Engineering-National Research Council will hold an important symposium on Thursday afternoon, October 5 during the International Steel Exposition at Detroit.

This committee has already done a great amount of valuable work on the subject of hardness testing and this meeting of the committee will undoubtedly have very important results.

The symposium will be in charge of Major A. E. Bellis, formerly Metallurgist, U. S. Armory, Springfield, Massachusetts.

In order that all those who are interested in this work may have the opportunity of entering the discussion, the committee has prepared a questionnaire in the attempt to arrive at comprehensive views of the opinions of those who are interested in the subject both from a practical as well as a theoretical standpoint.

It is desired that all those interested prepare their answers to this questionnaire and forward them to Major A. E. Bellis, Blake and Valley streets, New Haven, Connecticut.

If there are any opinions that are not covered by this questionnaire, it is requested that these ideas be incorporated along with the regular answers. In order to avoid restriction of space it is suggested that answers to the specific questions be given simply under the question number and other remarks or expressions of opinion be given in additional paragraphs.

It is imperative that these answers go forward to Major Bellis at the earliest possible time so that they may be reviewed prior to the convention meeting.

The program for the symposium meeting will be as follows:

OBJECT OF COMMITTEES, INVESTIGATION AND QUESTIONNAIRE by Major A. E. Bellis, Chairman of Committee on Hardness Testing of Materials.

SIGNIFICANCE OF HARDNESS TESTS by Dr. H. P. Hollnagel, General Electric Company.

HARDNESS AND ITS RELATION TO MAGNETIC PROPERTIES by Professor R. S. Williams, Oberlin College.

Questionnaire on Hardness Testing of Metals

DEFINITIONS

QUESTION NO. 1. What is your understanding of the term "hardness" based on you experience?

QUESTION NO. 2. If you recognize more than one definition, will you state all of the characteristics which the term applies to you?

QUESTION NO 3. Do you originally distinguish between different specific types of hardness, and what are the types?

QUESTION NO. 4. Can you suggest terms which could be better applied to qualities now commonly classed under the general term of hardness?

Testing Practice

QUESTION No. 5 Do you use any of the several methods at present exemplified by machines on the market?

QUESTION NO. 6. Do you use a different type of hardness testing machine for different purposes?

QUESTION NO. 7. Have you a method other than those referred to? If so, is this a method of your own design? (Please give details.)

QUESTION NO. 8. Is it specialized for a particular purpose?

QUESTION NO. 9. Are you willing to describe its character?

QUESTION NO. 10. Have the methods which you have ordinarily used given entire satisfaction for all kinds of materials?

QUESTION NO. 11. What correlation do you find between various machines?

QUESTION NO. 12. In determining hardness acquired by heat treating operations from a full anneal to the maximum hardness obtainable in any one steel by different methods (such as full impression and rebound types) do you find a satisfactory parallel from results of the different machines? Have you any data on curves?

Practical Considerations

QUESTION NO. 13. Do you use hardness tests as means to an end in any way whatsoever?

QUESTION NO. 14. Do you use the hardness number or measure for itself alone, or is it used to predict strength?

QUESTION NO. 15. Do you make hardness tests for your own information or to satisfy customers specifications?

QUESTION NO. 16. How important do you find information obtained from hardness tests to be? (Give a series of degree or comparative adjectives, which are vitally important.) Dollars and cents. Give degree of importance, as: Absolutely essential, very important, necessary, not essential, but desirable, useful if reliable, etc. Can you give any monetary estimate of their importance?

QUESTION NO. 17. Do you use the hardness test as a means for checking production?

QUESTION NO. 18. What relation do you recognize between hardness and:—

- (*a*) *Resistance to wear*
- (*b*) *Resistance to abrasion*
- (*c*) *Resistance to fatigue*
- (*d*) *Tensile strength*
- (*e*) *Elasticity*
- (*f*) *Compressibility*
- (*g*) *Toughness*
- (*h*) *Resistance to impact*
- (*j*) *Drilling, planing, turning and various machining detail operations*
- (*k*) *Tool presentation for best cutting conditions.*
- (*l*) *Other properties of metals.*

QUESTION NO. 19. Relationship between a surface and depth case hardness, such as a 1/16 thick case and a case hardness which goes all the way through a specimen?

QUESTION NO. 20. What is the maximum useful range of hardness tested for?

QUESTION NO. 21. Have you any information or theory on:

(*a*) *The relation of hardness to penetrability by X-rays.*
(*b*) *The relation of hardness to crystal structure.*
(*c*) *The relation of hardness to magnetic properties*
(*d*) *The relation of hardness to specific heat, thermal conductivity, and such allied properties.*

QUESTION NO. 22. The relation between hardness and amorphous content of metals.

QUESTION NO. 23. The relation between hardness and chemical activity.

QUESTION NO. 24. (*a*) *Is there any relation between hardness and and hysteresis?*
(*b*) *Is there any relation between hardness and coercive force?*
(*c*) *Is there any relation between hardness and residual magnetism?*
(*d*) *Is there any relation between hardness and the lower temperature at which a substance may be heat treated. For instance, in the neighborhood of 200 to 300 degrees Cent. in steel.*

QUESTION NO. 25. Is there a relation between hardness and specific gravity?

QUESTION NO. 36. Does increased hardness show a relationship with resistance to the change in specific gravity when the material is put under pressure?

Methods Relative to Use of Brinell Ball

QUESTION NO. 27. If you use the Brinell Ball for obtaining hard ness:—

(*a*) *What sort of machine is used for applying the load?*
(*b*) *What loads are used for various metals?*
(*c*) *What diameter of ball is used?*
(*d*) *Do you take account of rate of application of the load?*
(*e*) *How long is the load left on the specimen?*
(*f*) *Do you measure diameter or depth of impression?*
(*g*) *How is diameter or depth of impression measured?*
(*h*) *What basis is used for obtaining hardness number?*

(i) *Do you use any fixed type of specimen test?*

General Conditions

QUESTION NO. 28. What development of industrial hardness tests apply to—

(a) *Tests for thin sheet metal?*
(d) *Tests on very soft metals such as lead?*
(c) *Tests as to the general workability of metals?*
(d) *Tests on very soft metals such as lead?*

NEW HONORARY MEMBER

PROFESSOR Henry LeChatelier, Paris, France, has been elected to Honorary Membership in the American Society for Steel Treating.

The celebration of the 50th anniversary of his scientific career was recently celebrated in Paris and at that time Professor LeChatelier was notified and accepted his election as an Honorary Member.

His letter of acceptance follows:

Paris, France.
March 5, 1922.

President Gilligan:-

I have been greatly pleased at the honor your Society has conferred upon me by electing me an Honorary Member. I am deeply touched at your thoughtfulness in having this election coincident with the celebration of my Fiftieth Scientific Anniversary.

Will you act as my interpreter to your colleagues and express to them my great apprecation of the sentiments of regard and good will which they have extended to me.

Kindly accept the expression of my highest regard.

(Signed) Henri LeChatelier.

The following account of the scientific career of Professor LeChatelier has been largely extracted from the "Metallographist."

Henry Le Chatelier

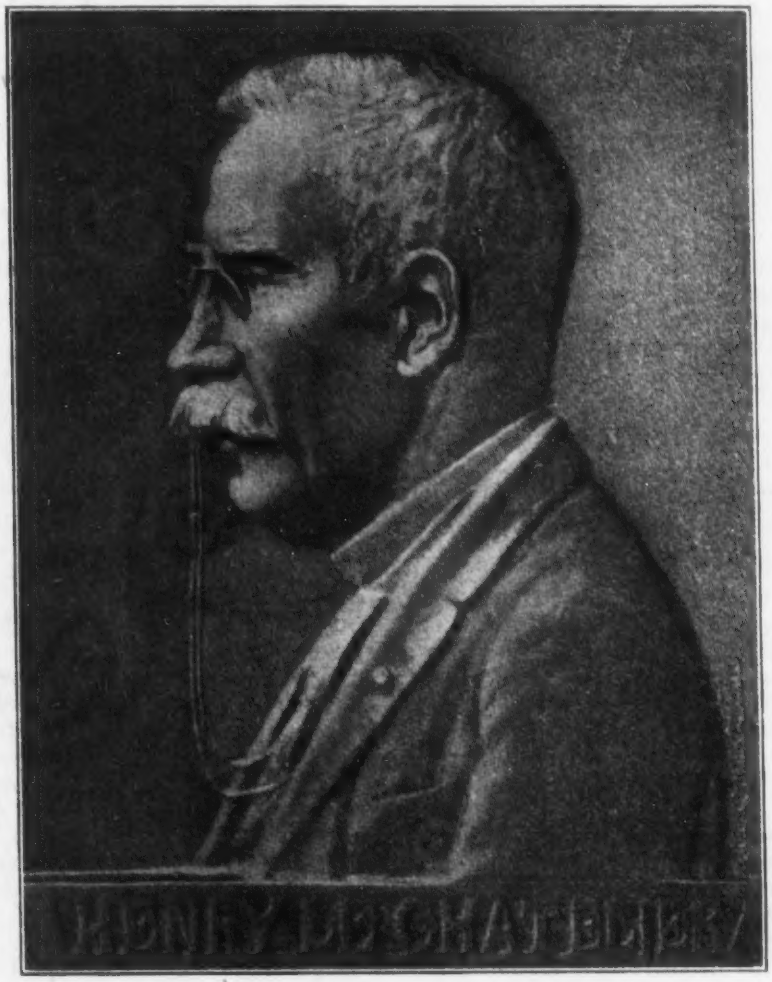
Henry Le Chatelier, so well known to all students of applied science, entered the Ecole Polytechnique at the head of his class in 1869. After graduating from this school in 1871, he spent three years at the Paris School of Mines, and upon leaving the School of Mines was sent to Algeria as a member of a commission whose mission was to ascertain the existence of a sea which was thought to have existed, in the past, in the deserts of Southern Algeria. Upon his return he practiced for two years the profession of engineer at the "Corps des Mines" of Besancon.

In 1877, Mr. Le Chatelier was appointed Professor of general chemistry at the Paris School of Mines, and in 1884 "interrogateur" at the Ecole Polytechnique, a position which he resigned in 1897. In 1884 he was the first choice of the Board of Improvement of the Ecole Polytechnique for the chair of Chemistry. In 1887 he gave up the chair of general chemistry at the Ecole des Mines to occupy that of industrial chemistry at the same school, a position which he still holds.

In 1892, he was awarded the Jerome Ponti prize, and in 1895 the La Caze prize.

In 1898, Mr. Le Chatelier was appointed Professor of mineral chemistry at the College de France, where he is the colleague of Professor Berthelot,

who occupies the chair of organic chemistry. Professor Le Chatelier is vice-president of the Chemical Society and of the Mineralogical Society; a member of the Committee of Applied Chemistry of the Societe d' Encouragement, foreign member of the Societe des Sciences of Holland, and member of many other scientific and technical societies. He is secretary of the Alloy Committee of the Society d' Encouragement, and the success of this important enterprise is due in a great measure to his untiring energy.



He is also the French member of council of the International Association for the testing of materials.

As Professor Le Chatelier himself says, the starting point of all his scientific investigations is to be found in his desire to apply scientific methods to industrial problems. Even his researches in pure science were suggested by industrial operations.

Professor Le Chatelier's scientific investigations and writings may be classified in two groups which at first sight appear quiet unrelated: Chemical Mechanics and Industrial Chemistry. These two departments of chemistry, however, as the author himself says, possess numerous points of contact. The laws of chemical mechanics control the phenomena of industrial chemistry as rigorously as they do the reactions in scientific laboratories.

His first researches dealt with hydraulic materials, and his numerous and valuable contributions to this important subject have given him a world-wide reputation among constructing engineers. The study of the dissociation of carbonate of lime was the starting-point of his researches in chemical mechanics as well as of those dealing with high temperatures.

Professor Le Chatelier's eminently successful researches dealing with the measurement of high temperatures are too well known to demand more than a passing notice. His thermo-electric couple is now in use in numerous industrial establishments where its usefulness could hardly be overestimated. This admirable pyrometer has made possible investigations of the greatest commercial and scientific importance in the physics of metals and alloys. The discovery by Osmond of the upper thermal critical points of iron and the scientific and systematic study of all the critical points of iron and steel, which have thrown so much light upon the constitution of steel, have been made possible by the use of the Le Chatelier thermo couple. Without it the construction of the fusibility curves of many metalic alloys, so invaluable in ascertaining the constitution of these alloys, would be a matter of great difficulty and much uncertainty. The discovery of the simple law connecting the temperature of the junction of the two metals and the electric current generated, which was the result of systematic and strictly scientific work is a monument which would satisfy the ambition of most physicists. Had Professor Le Chatelier done nothing more than this in the domain of pure and applied science, it would have sufficed to secure the gratitude and admiration of the scientific and industrial world. This discovery, however, which he has so generously presented to the world, constitutes only a relatively small part of his contributions to the advancement of science.

Professor Le Chatelier's investigations dealing with the setting of hydraulic material were the starting-point of his theoretical studies of the laws of solubility. These, in turn, suggested to him his experimental researches on the fusibility of mixtures of salts, and finally led him to investigate the constitution of metallic aloys, thus joining the ranks of those engaged in metallographic investigations. And we all know what valuable services he has already rendered both to the technology of the subject and to the interpretation of the results. Professor Le Chatelier showed that the fusibility curves of metallic alloys were in every way similar to the freezing curves of aqueous saline solutions or of mixtures of melted salts from which he inferred a similarity of constitution between these two classes of substances. These conclusions were in every particular confirmed by microscopical examination. According to the appearance of the curve of fusibility, he was led to classify all alloys into three groups, similar to those he had previously proposed for mixtures of salts, namely: (1) Alloys forming neither definite compounds nor isomorphous mixtures, (2) Alloys forming definite compounds and (3) Alloys forming isomorphous mixtures. To these three groups should be added a fourth one, including all alloys with abnormal curves of fusibility, and which future investigation will probably further subdivide. This modern theory of the constitution of alloys has been fruitful in deductions of industrial importance and will undoubtedly result in the abandonment of the empirical methods still in such extended use in the manufacture of metallic alloys.

After having thus studied the constitution of metallic alloys in general, it is quite natural that Professor Le Chatelier should have been attracted by the fascinating problem connected with the constitution of steel. To investigate this subject, he naturally adopted miscoscopical methods as one of the most promising means of advancing our knowledge of the true nature of steel. He entered this field exceptionally well equipped for effective experimental work. Fully aware of the importance of time-saving appliances in laboratory work as well as in industrial operations, he endeavored to shorten the required manipulations and especially to obtain some polishing powders which would greatly reduce the length of the polishing operation. The results of his investigations were published in full in the January, 1901, issue of "The Metallographist." He also devised a special microscope described in the same journal and recommended the use of the monochromatic light of a mercury arc vacuum lamp for photomicrography.

Professor Le Chatelier's discussion of the data upon which the modern theory of the constitution of steel has been erected is most valuable, notably his paper on "The Present Condition of the Theories of Hardening" and on "Iron and Steel from the Point of View of the Phase Doctrine," both of

which were published in full in "The Metallographist."

His experimental work dealing with the electrical resistance and with the dilation of steel, undertaken with a view of throwing additional light upon the allotrophic transformations of iron discovered by Osmund have yielded very important results. They have shown that the upper thermal retardation of iron (Ar3) occurring at about 850 degrees Cent., while often hardly noticeable by the calorimetric method, is on the contrary very marked when determined by the electrical method. This upper critical point always corresponds to an abrupt and very great alteration in the electrical resistance of iron. The second critical point on the contrary, occurring at about 750 degrees Cent., and the point of recalescence have hardly any effect upon the electrical resistance. His investigations on electrical conductibility were extended to nickel steel and to manganese steel, as well as to various non-ferrous alloys. They revealed the existence of some allotropic transformations in several alloys and notably in brass (at 730 degrees Cent.), in aluminum bronze (at 500 degrees Cent.), in zinc (at 350 degrees Cent.) and in an alloy of copper, iron and nickel (at 690 degrees Cent.).

It will be seen that besides being a distinguished metallographist, Professor Le Chatelier possesses many other titles; he has won an eminent position in several departments of pure and of applied science, through his experimental skill, scientific methods, erudition, and intellectual power.

Professor Le Chatelier has published over one hundred and twenty-five papers. He also wrote a book, in collaboration with Mr. Boudouard, on the "Measurement of High Temperatures," and translated into French the important work of Professor Gibbs on the equilibrium of chemical systems. The greatest number of his writings, by far, were published in the Comptes Rendus of the French Academy of Sciences, the others mostly in the Annales des Mines, the Revue generale des Sciences and the Bulletin of the Societe d' Encouragement."

The above is extracted from the "Metallographist" for October, 1901. Since that time Prof. Le Chatelier has continued his work and has contributed unstintingly to the advancement and improvement of the Metallurgy of Steel. Since 1901 he has written something over one hundred papers on metallurgical and allied subjects. In partial recognition of his work he has been awarded the Bessemer Gold Medal by the British Iron and Steel Institute.

THE EFFECT OF STRUCTURE UPON THE MACHINING OF TOOL STEEL

By J. V. Emmons

Abstract of Paper

This paper discusses the effect of the hardness and the structure of tool steel upon its machinability. Detailed observations have been made of the effect of the various structural constituents upon its machinability. The machining operations considered are turning, milling, drilling, reaming, thread cutting, swaging, wire drawing, punching and shearing.

General conclusions are drawn as to the most favorable structures for the various machining processes. Explanations of many of the difficulties encountered in machining tool steel are offered, and the way is pointed out for the development of annealing processes to secure the desired machinability.

IN THE manufacture of tools, the question of proper machinability is one of the highest importance. In the present age of quantity production, low machining costs are absolutely essential to the success of many tool making enterprises. The question of obtaining a suitable machined finish upon certain tools is often the deciding factor in the purchase of tool steel. The spoiled work due to unsatisfactory machining often causes losses which appall the tool maker. Often the feasibility of manufacturing delicate tools requiring a high degree of accuracy depends upon obtaining a tool steel of more than average machinability. The following observations were made in the course of a study of the effect of the structure of tool steel upon the various machining operations which were performed upon it. This work was begun in 1910 and extended through a period of about 5 years to 1915. The accuracy of the conclusions has been confirmed by their successful application to commercial work during the succeeding 7 years.

A great deal of confusion has arisen from the fact that steels which machine easily are called "soft" and those with which difficulty is encountered are called "hard." "Hard to machine" is a common expression in every machine shop. Actually, the meaning is "difficult to machine." The word hard, meaning difficult, is thus easily confused with the word hard meaning the property of mineralogical hardness. It is thus concluded that the softer the steel, the greater the ease of machining and vice versa the harder the steel, the greater the difficulty which will be encountered in cutting it. This conclusion is undoubtedly true in some cases, but the exceptions are so many and so important that it should not be considered as a general rule. For instance, the effect of the structure upon the machining properties of tool steel has been found to be so great than in many cases it overshadows the effect of the hardness. As a means of estimating the machinability of tool steel, a knowledge of the structure is fully as important as a knowledge

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A paper to be presented before the Detroit Convention, October 2-7. The author, J. V. Emmons, is metallurgist, the Cleveland Twist Drill Co., Cleveland, O.

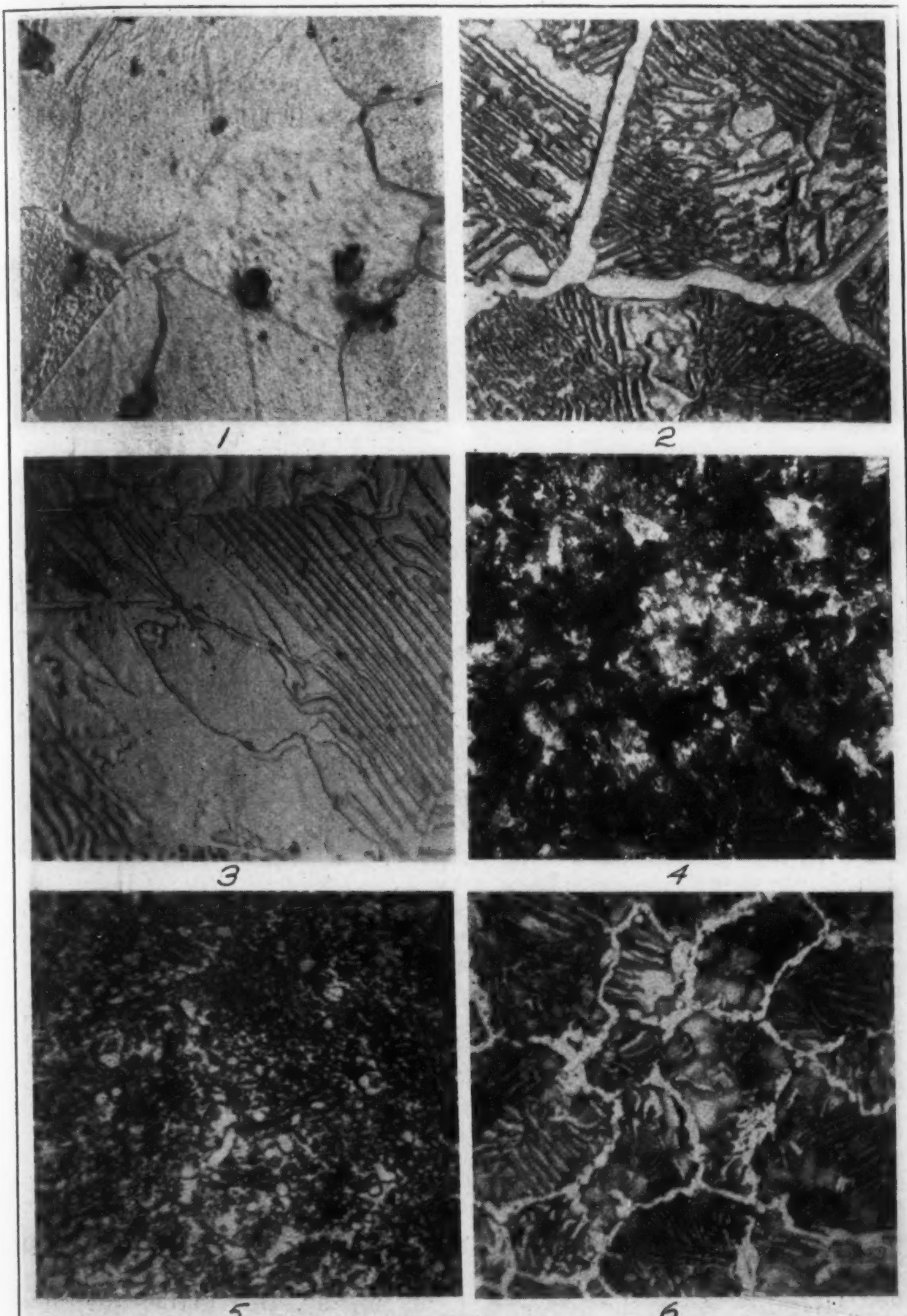

Fig. 1—The structure of pure ferrite. X 750. Fig. 2—Large network of massive cementite. X 750. Fig. 3—Pearlite showing both longitudinal and cross sections of the plates. X 750. Fig. 4—Sorbite. X 75. Fig. 5—Sorbite with rounded particles of massive cementite. X 1500. Fig. 6—Pearlite with network of massive cementite. X 1500.

of the hardness. A study of both hardness and structure together gives an index to the machinability of tool steel of surprising accuracy.

The series of experiments, the results of which are herein embodied was planned to show the detailed effect of the various microconstituents upon the machinability of the steel. Austenite, martensite and troostite were eliminated from consideration as they are obviously too difficult to machine to be considered a commercial possibility. The field was thus narrowed down to a consideration of sorbite, pearlite, ferrite, massive cementite and spheroidized cementite. The investigation is based upon plain carbon steels containing over 1.00 per cent carbon and no added alloy. Any deviation from these conditions is noted specifically. The machining operations under observation were: turning, milling, drilling, reaming, thread cutting, swaging, wire drawing, punching and shearing. The nature of each of the above mentioned microconstituents should be briefly reviewed in order to understand its effect upon a cutting tool.

Ferrite

Ferrite being carbonless iron is very soft and easily cut. It is also tough and easily deformed. In tensile tests, it has a high elongation and reduction of area. If pure its behavior during machining is that it cuts easily and with little wear upon the cutting tool. It is especially liable to gum up the tool, adhering to the cutting edge, creating excessive friction and frequently generating sufficient heat in this manner to draw the temper of the cutting tool. It also tears badly due to its great tenacity, particularly when cut with tools having little clearance and rake such as milling cutters and threading dies. This tearing, together with the friction of chips adhering to the cutting edge produces a rough finish very unsatisfactory for most requirements. The microstructure of commercially pure ferrite is shown in Fig. 1.

Cementite

Cementite or carbide of iron is very hard and brittle. It is too hard to be cut by the average cutting tool and in tool steel can only be broken and pushed to one side by the advancing cutting edge. Due to its great hardness, it abrades the cutting tool very rapidly. The larger the cementite particles, the rougher the machined surface will be. A distinction can sometimes be made in the kinds of cementite as follows: 1. Massive cementite is that portion in excess of the amount required to form pearlite. It is usually present in larger masses than the eutectoid cementite and frequently forms a network at the grain boundaries. 2. Spheroidized cementite is the product of the precipitation of the eutectoid cementite in rounded or globular form, shown in photomicrograph Fig. 2.

Pearlite

Pearlite being a definite alloy which consists of alternate plates of ferrite and cementite, unites the toughness of the former with the hardness of the latter. Pearlite, therefore, tears badly, leaving a rough surface and at the same time wears out the cutting tool rapidly. The microstructure of pearlite is shown in Fig. 3.

Sorbite

Sorbite, due to its combined hardness and tenacity exerts a great abrasive action upon the cutting tool wearing it out rapidly. Due to the fine state of division of its cementite particles, it is possible to produce a very smooth finish upon the machined surface. Fig. 4 shows the structure of sorbite at 75 diameters magnification. While these observations are interesting, it should be noted they are made in reference to the pure unmixed constituents.

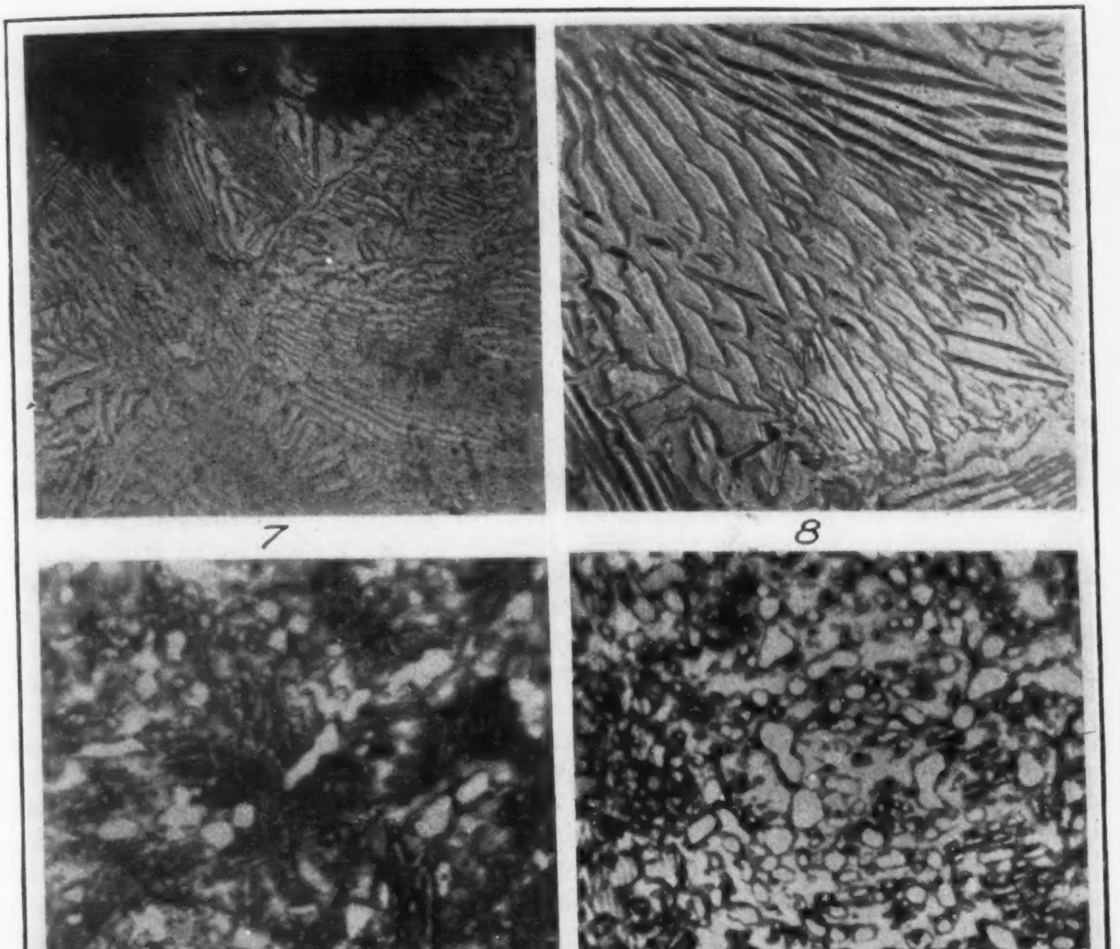

Fig. 7—One edge of crack passing through pearlite. X 375. Fig. 8—Illustrating tendency of cementite plates to break into sharp splinters. X 750. Fig. 9—Pearlite, sorbite, and massive cementite. X 1500. Fig. 10—Sorbite, ferrite, spheroidized and massive cementite. The sorbite is well coagulated. X 1500. Fig. 11—Ferrite and massive cementite in large masses. X 1500. Fig. 12—Partially spheroidized cementite with about 50 per cent pearlite. X 750.

Annealed tool steel invariably consists of a mixture of not less than two and sometimes more of these constituents. The problem is thereby somewhat complicated. The most common combinations met with are as follows:

1. Sorbite and massive cementite.
2. Pearlite and massive cementite.
3. Pearlite, sorbite and massive cementite.
4. Sorbite, ferrite, spheroidized and massive cementite.
5. Pearlite, ferrite, spheroidized and massive cementite.
6. Ferrite, spheroidized and massive cementite.

These will be considered in more detail. It should be noted that the first three combinations are difficult to machine and are generally to be avoided. The latter three all have specific uses and from them satisfactory structures can be selected for almost every machining operation.

Sorbite and Massive Cementite

"Sorbite and massive cementite" are formed by two common processes. The first consists of cooling the steel from above the critical point with moderate rapidity. The second consists of quenching the steel from above the critical point and then drawing back to about 1200 degrees Fahr. This combination has a scleroscope hardness of 40 to 50 and a Brinell number of from 210 to 300. It can be machined, if slow speeds are used and the tools reground frequently. The finish produced is smooth and for this reason it has been sometimes used for the production of taps and thread gages where a smooth finish is essential. Satisfactory wire can be drawn from it as its ductility is high. Turning, milling, drilling and thread cutting can all be performed if care is taken, but the speed will be of necessity slow and the tool cost high. Swaging, punching and shearing, present such difficulties that it is scarcely feasible to even attempt them. In order to secure a satisfactory smoothness of finish which is the only possible excuse for using this structure, it is essential that the massive cementite be broken up into as small particles as possible and especially it must not be present in the form of a network. Fig. 5 shows sorbite and massive cementite at 1500 diameters magnification.

Pearlite and Massive Cementite

"Pearlite and massive cementite" is a combination that appears to make no friends among the machining operations. Fig. 6 shows a photomicrograph of this structure taken at 1500 diameters magnification. It turns rough and wears out the tools rapidly. It tears badly in milling and thread cutting. Drilling can be done successfully, if the drills are reground frequently. Reamers, however, are worn undersize with great rapidity. In swaging and wire drawing, the dies wear rapidly and the finished size will not run uniform. In punching while shearing there is apt to be a serious loss due to the stock cracking and the punches and dies wear out with great rapidity. This behavior of pearlite and massive cementite is so marked that a special investigation has been made to throw more light upon the reasons for its unsatisfactory machinability. The hardness of this combination varies from 40 to 46 scleroscope and from 220 to 300 Brinell being in this respect not much different from the sorbite and cementite combination. It is, therefore, obvious that the marked differences in machining behavior between the two combinations are not due to the hardness.

A careful examination of pearlite structures revealed the facts that pearlite is always present in grains of considerable size; that cracks

passing through pearlite prefer to follow the grain boundaries or if they pass through the grains to follow the laminations, as in Fig. 7. It was also observed that a cutting edge working in pearlite is usually preceded by a crack which runs ahead of the advancing edge as it wedges its way through the steel. The reason for the rough surface of machined pearlite was then apparent, that is, the machined surface is actually the rough fracture of the pearlite grains torn apart by tension. The rough surface is, however, more or less smoothed down after the initial rupture by the following cutting edge shearing off the high points.

The other peculiarity of pearlite, namely, its greater abrading action than sorbite of the same hardness is explained as follows: The cementite particles in sorbite are for the most part in round or rounded forms. The abrasive action of sorbite may, therefore, be likened to that of a grinding wheel with round emery for the abrasive. The cutting edge as it advances pushes the round cementite particles to one side and they slide readily over it. In pearlite, however, the cementite particles are in the form of flat plates of considerable size. As the cutting edge advances, the metal becomes distorted under the extreme pressures and the brittle cementite plates are broken into countless sharp cornered splinters. These sharp splinters firmly held in the matrix of ferrite exert an abrasive action similar to that of a grinding wheel with sharp emery for its cutting medium. The result is that the cutting tool is worn away with great rapidity. Fig. 8 shows this structure at 750 diameters magnification.

In this connection the observation should be recorded that massive cementite when present with the pearlite in a large network seems to increase the wearing effect upon the cutting tool very materially. This is probably due to the large size of the cementite splinters formed by the crushing of the network. It has also been observed that the higher the carbon content of the steel when in the pearlitic condition, the greater wear upon the cutting tool. This is undoubtedly due to the increased percentage of massive cementite with the corresponding increase in the number of abrading particles. From the above observations, the simple rule has been deduced; that the larger the grain size and more distinctly lamellar the pearlite, the greater the difficulty of machining. In practice this rule has been found to hold almost without exception.

Pearlite, Sorbite and Massive Cementite

The combination of pearlite, sorbite and massive cementite is not of such common occurrence as the preceding combination. It is, however, frequently found in steel that has been normalized, that is, heated considerably above the critical point and either air cooled or semi-annealed by plunging in line or ashes. Fig. 9 shows this structure at 1500 diameters magnification. This combination is machinable if slow speeds and extra hard tools be used, but it would be difficult to get any reasonable production from it. While its hardness is usually somewhat greater than that of pearlite produced by a slower cooling, it is somewhat easier to machine because the pearlite has not had time to assume a coarsely lamellar structure and the massive cementite has not been rejected to the grain boundaries to form a network. The principle reason for intentionally producing this structure would be to obtain a quick anneal where time was of more importance than ease of machining.

Sorbite, Ferrite, Spheroidized and Massive Cementite

The combination of sorbite, ferrite, spheroidized and massive cementite is the hardest combination that it has been found feasible to machine in reg-

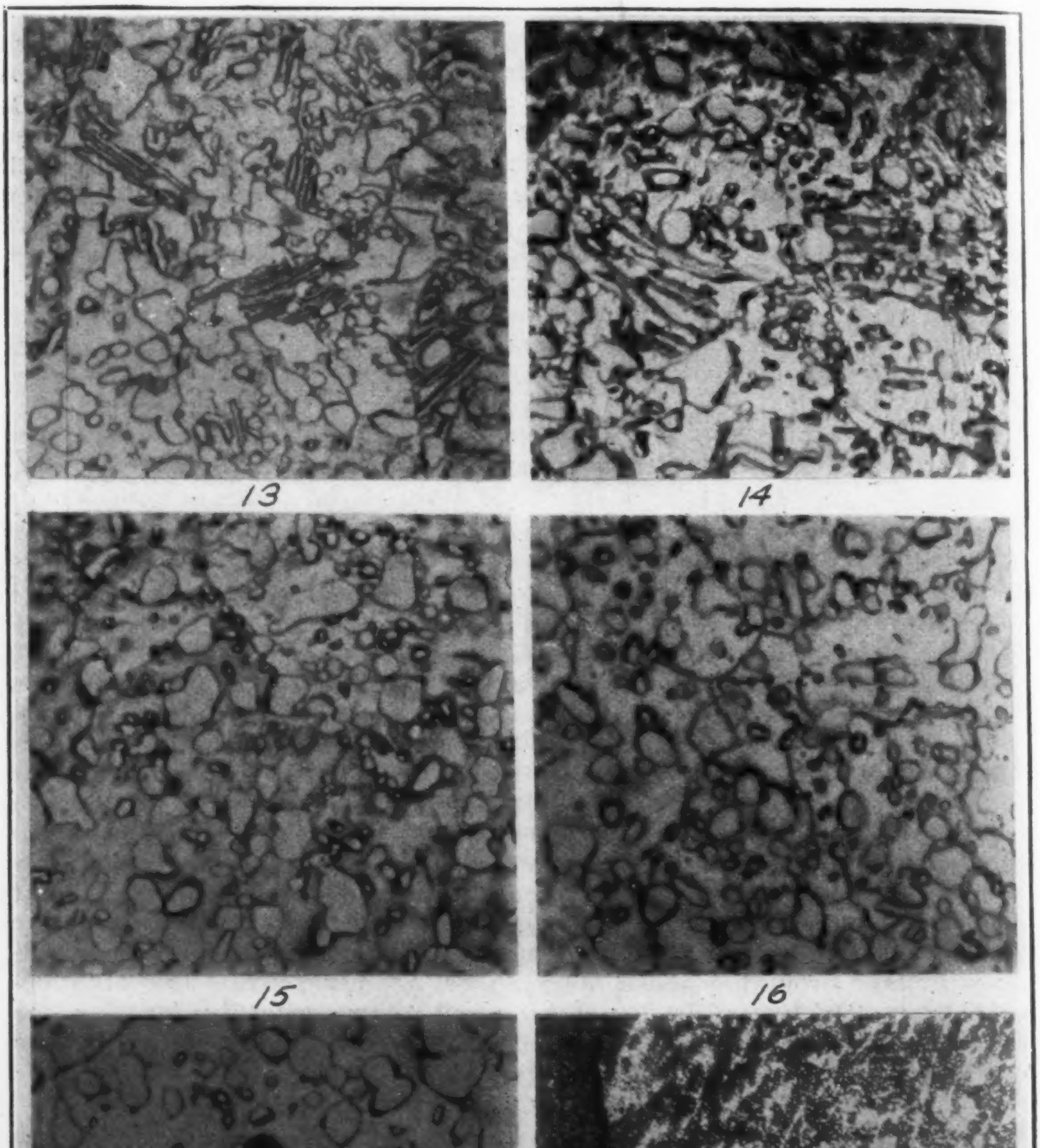

Fig. 13—Partially spheroidized cementite with about 25 per cent pearlite. X 1500. Fig. 14—Partially spheroidized cementite with trace of pearlite remaining. X 1500. Fig. 15—Completely spheroidized cementite. No ferrite grains. X 1500. Fig. 16—Completely spheroidized cementite. Ferrite shows grain structure. X 1500. Fig. 17—Completely spheroidized cementite. The ferrite shows grain structure. Graphite beginning to precipitate. X 1500. Fig. 18—Portion of an oval segregation of cementite. The normal structure of the piece is shown upon the left. X 75.

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entite.

ular production work. It is produced commonly by two methods: First by reannealing steel which has been previously spheroidized at a temperature only slightly above the Ac point and then cooling with moderate rapidity. The second method is to add an element such as chromium which tends to prevent the formation of lamellar pearlite. With such alloy steels the sorbite persists through much slower cooling than is the case with carbon steels. The coagulation of the sorbite also requires a much longer time, so that it is frequently uncompleted with ordinary annealing, Fig. 10.

This combination is machinable in proportion to the completeness with which the sorbite has coagulated. This is believed to be on account of the cementite particles becoming fewer and more rounded. It is sometimes quite difficult to determine when the sorbite has completely passed over into the spheroidized condition. As the coagulation proceeds, the ferrite areas at the same time become larger and more continuous, thus affording an easier passage for the cutting tool and lessening the abrasive effect. The machined surface of this combination is usually very smooth unless the coagulation has proceeded so far that the cementite has gathered in large masses separated by large areas of ferrite as shown in Fig. 11. In this case the steel is apt to machine gummy and tear easily. This tearing is particularly noticeable if the ferrite has begun to assume its characteristic grain structure with well marked grain boundaries. While a very large tonnage of steel with this structure is machined by all the common machining operations, it must still be regarded as inferior in machinabilty to the next combination to be considered.

Pearlite, Ferrite, Spheroidized and Massive Cementite

This is the most interesting combination of all the structures in tool steel because of its great variations in machinability, according to the percentage of the various constituents present. This structure is produced by slow cooling through the critical range to allow the slow deposition of the cementite from solution upon the massive cementite. When the Ar point is passed only enough cementite remains in solution to form a broken lamellar structure of pearlite. It is necessary that the cooling be sufficiently rapid to prevent the complete spheroidization of the cementite. All variations of this structure may be produced at will by varying the rate of cooling between the Ac and the Ar points. With a high percentage of pearlite the steel machines with practically all the difficulties noted in the case of the combination of "pearlite and massive cementite." As the percentage declines, however, the machining becomes more satisfactory. When the pearlite occupies about 50 per cent of the area, the machined surfaces become more smooth, particularly with the milling and thread cutting operations. This structure is shown in Fig. 12. The wear on the tools is, however, still quite heavy. Steel in this condition usually causes complaint from the turning, swaging, punching and shearing operations because of the frequent re-sharpening required by the tools and dies. The milling and thread cutting operations are, however, usually well satisfied because the satisfactory finish upon the work more than compensates them for the extra wear on the cutting edges.

When only about 25 per cent of lamellar pearlite remains, we have a structure of peculiar interest because it seems to be a happy medium which gives general satisfaction to all of the machining operations. (Fig. 13.) The turning is smooth and can be performed rapidly with a reasonable amount of production between regrinds of the tools. The milling is also smooth and free from tearing even at high speeds and heavy feeds. Thread cutting

is also satisfactory, the threads being sharp and clean with little burr. Drilling, reaming and other operations can be performed with satisfactory results. The peculiarly satisfactory results obtained from this structure are due to the fact that the eutectoid cementite is now almost completely broken up into rounded masses which no longer wear out the cutting tool with their former rapidity. The massive cementite is also in rounded masses easily pushed aside by the cutting edge. The ferrite areas are developed just sufficiently to allow easy passage to the cutting edge, but not enough to make it gum up and tear. While this structure appears to be the most satisfactory one when all the different operations are done upon one piece, it does not necessarily follow that it is the most satisfactory one for each and every operation. In fact, turning, swaging, drilling and frequently punching and shearing will have their requirements better satisfied with a softer steel.

The hardness with 25 per cent pearlite is about 32 to 38 scleroscope, while the Brinell is from 190 to 230. In order to secure a softer steel the spheroidization is pushed forward to completion. This reduces the scleroscope hardness to about 28 to 32 and the Brinell number to about 170 to 190 at the point where the last traces of pearlite laminations are disappearing as shown in Fig. 14. This change has been found to improve the machinability with respect to turning, drilling, swaging, punching and shearing. The milling and thread cutting, however, show increased roughness of surface and tendency to throw up a burr. Any further progress of the spheroidization removes the last traces of the pearlite laminations and leaves us with the last one of the structures of particular interest in machining.

Ferrite, Spheroidized and Massive Cementite

The structure now consists of rounded particles of cementite imbedded in a matrix of ferrite. (Fig. 15.) The ferrite, however, may or may not have developed its typical grain structure. (Fig. 16.) Steel of this structural type which has well developed ferrite grains is in the softest state it is possible for it to acquire without destroying some of its quality. In order to produce this complete spheroidization, it is necessary to prolong the time in passing through the Ac to the Ar region to a considerable length. Several hours are sometimes necessary to insure that the formation of pearlite is completely inhibited. This structure has a scleroscope hardness of from 25 to 32 and a Brinell hardness from 160 to 190.

For the operations of turning and swaging, this structure is ideal. For the other operations it is usually found too soft. Thread cutting is almost out of the question on account of the steel tearing badly and the tool hogging in. Milling is almost as bad, the soft gummy chips clogging the cutters and producing rough work. Steel with this structure is almost invariably pronounced hard in milling and tapping. This is a typical example of steel which is called "hard" when the actual meaning is "difficult to machine." Drilling can be performed successfully, but there is always a tendency for the drill point to hog in, or grab, breaking the drill. Reaming must be done carefully with a good lubricant as the gummy chips tend to ahere to the cutting edge producing rough holes. This structure performs well in wire drawing, but in punching and shearing the deformation is frequently excessive. It should be here noted that attempts to produce this structure of completely spheroidized cementite by slow cooling through the critical range if carried to extremes will result in the precipitation of part of the carbon as graphite, as shown in Fig. 17. This formation of graphite if in any considerable quantity renders

the steel inferior, if not actually useless due to its diminished hardening power. Great care is, therefore, necessary if this structure is to be produced upon a commercial basis.

In conclusion there are two freak structures which frequently cause considerable difficulty in the machining of tool steel. The difficulty is in-

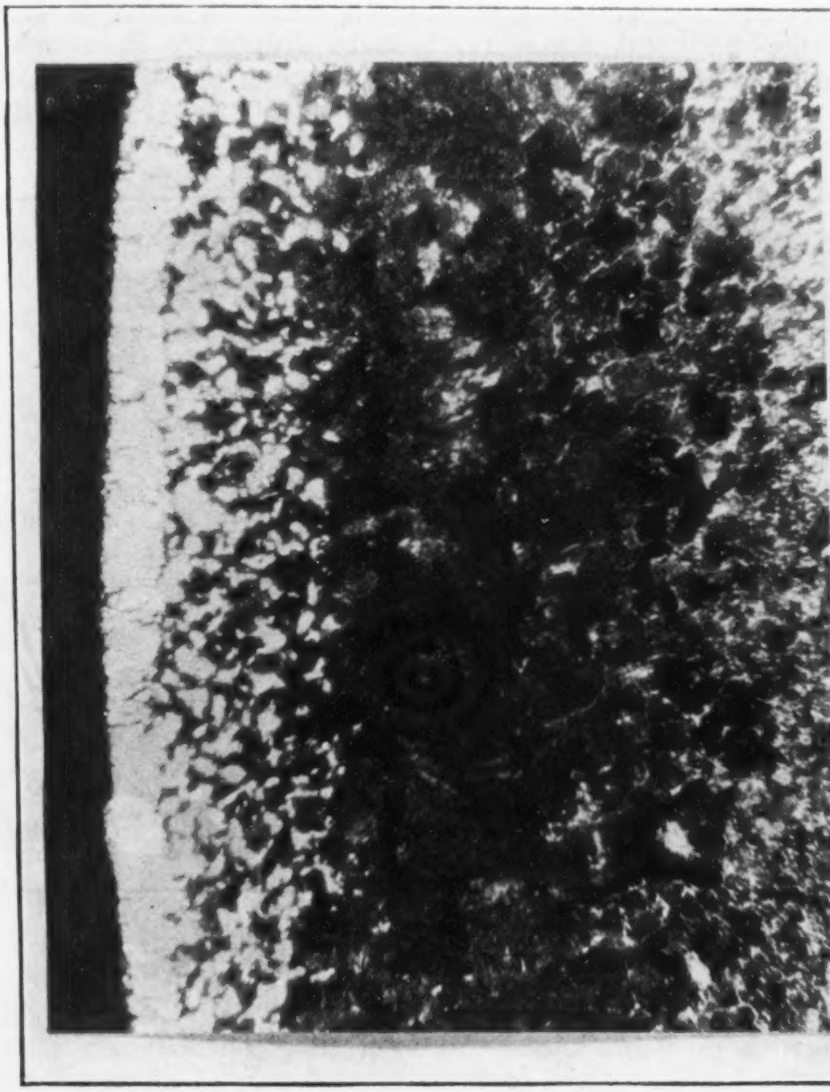


Fig. 19—Decarburized bark. Outside of the bar is on left. Normal structure of interior on extreme right. X 75.

creased by the fact that their presence is often unknown and hard to detect. I refer to segregations of cementite and to surface decarburization, or as it is commonly known, "bark."

Cementite Segregations

Hard spots are frequently met with in machining tool steel. These spots instantly dull or destroy the cutting edge of the tool. In the majority of cases these are found to be cementite segregations. Cementite segregations are difficult to detect unless they are present in large numbers, when they can be best located by the microscope. See Fig. 18. It occasionally happens that a few segregations in a lot of steel otherwise of satisfactory machinability

dull the tools in a manner that makes the true cause very difficult to locate. In such a case, the hardness tests and the microstructure may both appear good and the investigator is at a loss to explain why the steel should behave so badly.

Decarburized Bark

Decarburized bark has of necessity a structure different from the interior of the steel and, therefore, behaves differently in machining. Bark is never considered to be beneficial to a machining operation, but is a defective portion to be removed by machining. Fig. 19 shows this defect. Turning, shaping and planing are the principle operations to be affected by the

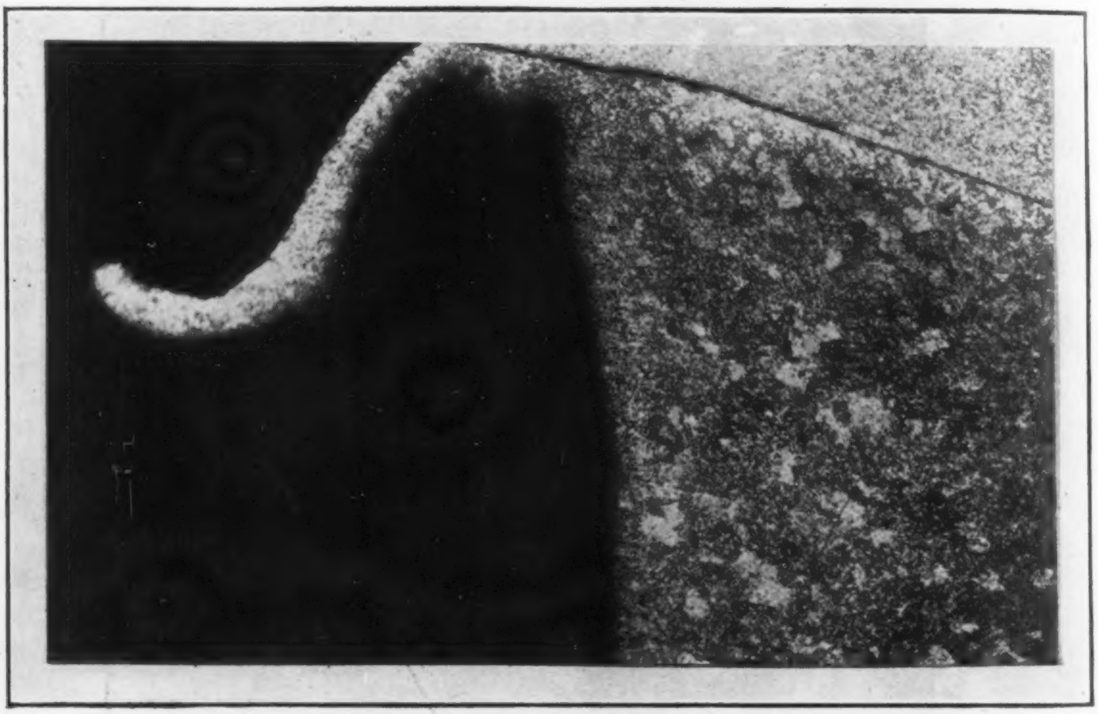


Fig. 20—Heavy burr in milling caused by slight ferrite bark. X 150.

bark. Even when the interior of the steel is completely spheroidized, the bark frequently contains a large percentage of lamellar pearlite which wears out a tool with great rapidity. An interesting phenomenon is frequently noted when the outside of the bark consists of a band of pure ferrite below which is a layer of pearlite and below this the more or less spheroidized interior of the steel. When a round bar having such a bark is turned, the pearlite ring constantly revolving against the same portion of the lathe tool actually wears a nick in the tool, while the portion of the tool cutting on each side of the pearlite is unaffected. The presence of bark especially a ferrite bark frequently causes a heavy burr in milling even though the interior of the steel may be in perfect condition to mill. This condition is shown in Fig. 20.

Conclusion

To sum up the observations detailed above, it may be stated that when a single machining operation is to be performed upon tool steel and the

(*Concluded on page* 1212)

CASE HARDENING

By A. H. d'Arcambal

Abstract of Paper

Tests conducted on samples of low carbon steel, cyanide treated, showed that the hardness obtained on cyanide hardened parts is due both to the absorbed carbon and nitrogen, principally to the latter (iron nitride). The higher the temperature (up to 1550 *degrees Fahr.) and the longer the time of immersion, the greater percentage of these two elements were found. The combined nitrogen in the areas of highest nitrogen concentration appeared as pearlite patches and in the less concentrated sections as needles.*

Izod notched bar tests, conducted on plain carbon and alloy case hardening steels, showed that of the specimens carburized and double treated, the S.A.E. 6120 *steels gave the highest impact readings, closely followed by the S.A.E.* 2315 *steels. The S.A.E.* 3115 *steels gave the lowest readings of the alloy steels tested. The S.A.E.* 1015 *and* 1112 *steels gave very low readings after carburizing and double quenching. All of the alloy steels showed lower impact readings after carburizing and single quenching for case refinement only, than was found on the specimens double treated after carburizing. The core fractures on the single treated specimens also showed a coarse grained structure, as compared with the fine grained fractures obtained on the double treated specimens.*

Impact tests were also conducted on the different types of steels, packed in sand instead of carburizing compound, and then double and single treated. The results on these double treated specimens ran as follows, from highest to lowest S.A.E. 1015, 6115 1112, 2315 *and* 3115. *The high results obtained on the* 1015 *and* 1112 *specimens were due to the softness of the material* (150-200 *Brinell), as compared with the hardness obtained on the alloy steels* (250-400 *Brinell).*

Static tensile tests on specimens of S.A.E. 6120 *and* 1015 *steels, sand treated, then double and single quenched showed that while greater tensile strength was obtained on the single treated specimens, this increased strength was gained at the expense of the ductility of the material.*

* * *

This paper on Case Hardening is divided into 2 parts, the first part being a study of the chemical reactions taking place in the cyanide process of case hardening, the remainder of the article giving the results of Izod notched bar tests on several well known types of case hardening steels.

Part I

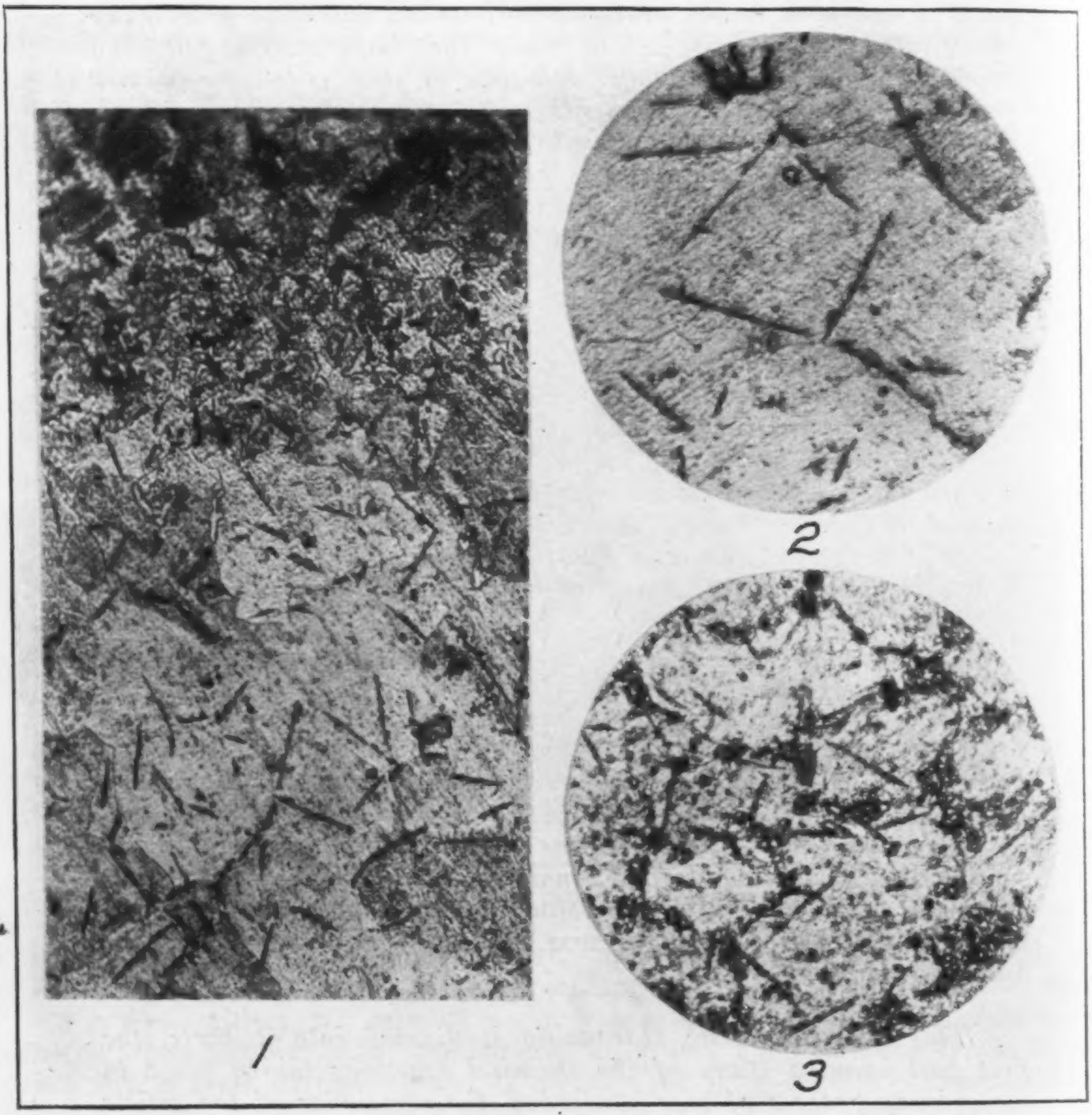
VERY few articles have been published on the true action of cyanide in the case hardening of steel. Papers by Brophy and Leiter[1], Hillman[2], and Shimer[3], attack this interesting subject from different angles and contain valuable information to all interested in the cyanide process of case hardening. In order to obtain additional information as to the chemical reactions occurriing in the cyanide hardening of steel, tests were conducted on

1, 2, 3. See foot note next page.

A paper to be presented before the Detroit Convention, October 2-7. The author, A. H. d'Arcambal, is metallurgist, Pratt & Whitney Co., Hartford, Conn.

samples of plain carbon case hardening steels, the results of these tests being given in Table I and photomicrographs in Figs. 1, 2 and 3. The following information is gained from these tests:

1. Steels given the cyanide treatment are both carburized and nitrogenized, the resulting hardness however, being due principally to the



CYANIDE TREATED SPECIMENS

Fig. 1—S. A. E. 1015 steel. 1 inch round specimen immersed in 76 per cent sodium cyanide bath at 1550 degrees Fahr. for 90 minutes, lime cooled, reheated to 1500 degrees Fahr., brine quenched, then annealed at 1600 degrees Fahr. X 250. Fig. 2—S. A. E. 1015 steel. Same as above. X 500. Fig. 3—S. A. E. 1112 steel. ⅜-inch round specimen immersed in 76 per cent sodium cyanide bath at 1550 degrees Fahr. for 100 hours, lime cooled, reheated same as specimen Fig. 1. X 500.

absorbed nitrogen, as the carbon is too low to produce file hardness. As medium carbon steels containing over 0.045 per cent nitrogen possess no ductility whatsoever[4], one can thus see the cause of brittleness in cy-

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1. "True Action of Cyanide in Case Hardening of Steel," by Brophy and Leiter." *Transactions* of the American Society for Steel Treating. Vol. I, No. 6.
2. "Efficiency of Different Mixtures for Cyanide Hardening," by V. E. Hillman. *Transactions* of American Society for Steel Treating. Vol. II, No. 4.
3. "Cyanide in Liquid Case Hardening," by P. & E. B. Shimer. *Transactions* of the American Society for Steel Treating. Vol. II, No. 5.

anide treated objects. It is claimed that nitrogen causes greater brittleness in higher carbon steels than in steels of low carbon content. We can therefore see the folly of using a cyanide bath for reheating carburized specimens or as a heating medium for carbon tool steels.

2. The amount of carbon and nitrogen absorbed is dependent on the time and temperature, the higher the temperature and longer the time,

Table I

Carbon and Nitrogen* Determinations in Per Cent

Specimen No.	Treatment	1st .010-inch removed from O.D. Car.	Nitr.	2nd .010-inch removed from O.D. Car.	Nitr.	3rd .010-inch removed from O.D. Car.	Nitr.	4th .010-inch removed from O.D. Car.	Nitr.	Center drillings** Car.	Nitr.
1	45 mins. in cyanide bath at 1550 degrees Fahr. cooled in lime.	.44	.353	.22	.036	.18	.017	.14	.009	.14	.006
2	75 mins. in cyanide bath at 1550 degress Fahr. cooled in lime.	.52	.372	.32	.048	.21	.028	.14	.013	.14	.006
3	120 mins. in cyanide bath at 1550 degress Fahr. cooled in lime.	.56	.451	.39	.077	.19	.029	.15	.014	.14	.008
4	45 mins. in cyanide bath at 1450 degrees Fahr. cooled in lime.	.30	.215	.22	.044	.15	.027	.15	.019	.14	.009
5	220 mins. in cyanide bath at 1450 degrees Fahr. cooled in lime.	.61	.467	...	...	...	...	...	...	...	...

76 per cent sodium cyanide used.

Size of test pieces—1¼-inches dia. x 8 inches long.

Analysis of steel used for the test specimens—

Carbon	.14	per cent
Manganese	.62	per cent
Phosphorus	.020	per cent
Sulphur	.064	per cent
Nitrogen	.0033	per cent

*—The method of analysis used is the one recommended by the bureau of standards and gives only the combined nitrogen (iron nitride).

**—¼-inch drill used.

the greater percentage of these two elements are found.

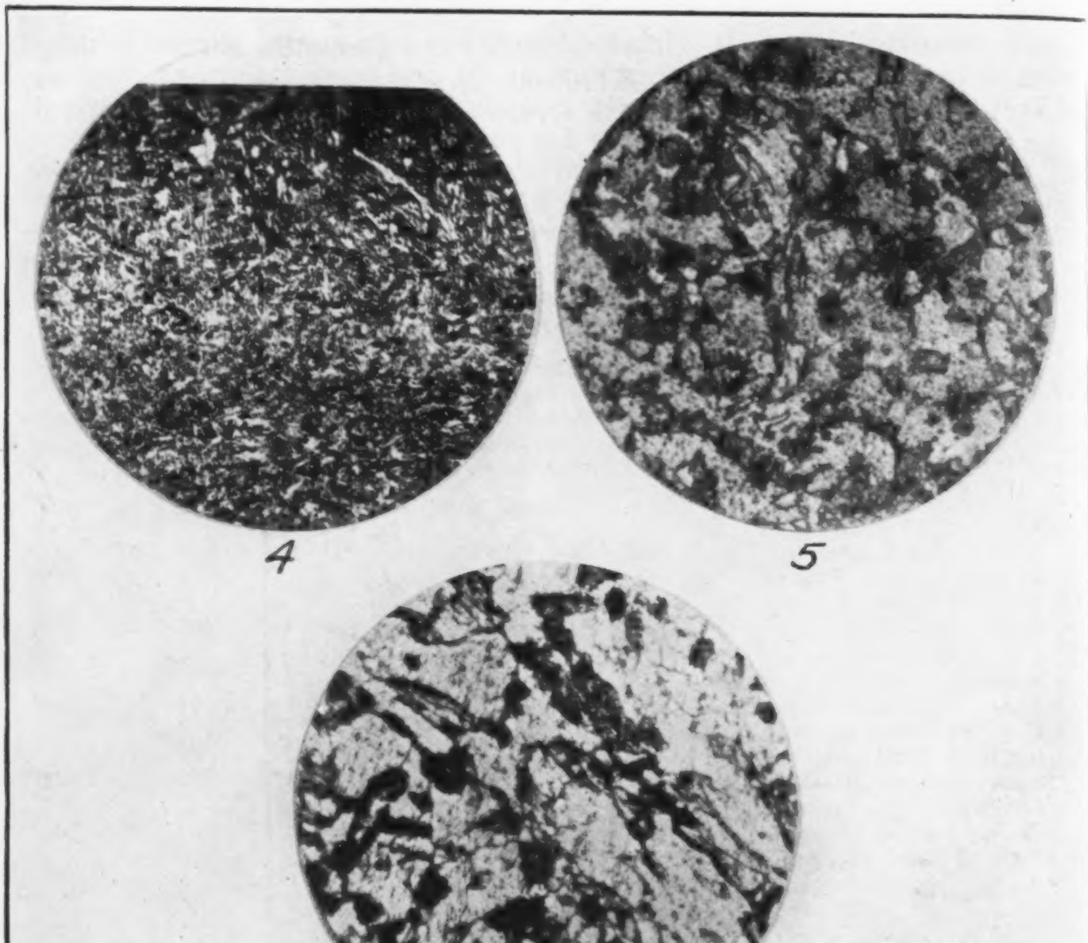
3. The highest concentration of nitrogen and carbon is found in the first 0.005-inch layer removed from the outside diameter of the cyanide treated specimens. The second layer removed from the samples contain less than 1/5 the amount of combined nitrogen found in the first layer.

4. Nitrogen penetrates the material to a slight extent throughout the cross section as is shown by the analysis of the center drillings.

5. The nitride needles are not found in the areas showing the highest concentration of nitrogen but are located near the breaking off point of the case. The nitrogen in the concentrated area appears as patches of pearlite.

6. The depth of case measures about the same in each of these samples, that is from 0.008 to .010 inch deep. A longer time at tem-

4. Article in *Stahl & Eisen*. Vol. 25, Page 1195, by H. Braune.



CASE HARDENED SPECIMENS
S. A. E. 1015 Steel (A)

Fig. 4—Case structure on impact specimens double heat treated after carburizing. X 500. Fig. 5—Core structure on impact specimens double heat treated after carburizing. X 500. Fig. 6—Core structure on specimen quenched from pot, then single quenched for case. X 500. Fig. 7—Case structure on impact specimen single heated after carburizing. X 500. Fig. 8—Core structure on impact specimen single treated after carburizing. X 500.

perature therefore does not increase the total depth of penetration but does produce a greater concentration of carbon and nitrogen near the outside surface.

A sample of 3/8-inch screw stock was immersed in a sodium cyanide bath at 1500 degrees Fahr. for 100 hours and cooled in lime. A small section of the sample was hardened and fractured, the depth of case measuring about 0.070 inch. The total case on the unhardened specimen was sampled, the analysis of the same being as follows:

Carbon	.40%
Combined Nitrogen	.129%

The micrograph of this sample shows a few nitride needles present and the breaking up of the pearlite.

Part II

Izod Notched Bar Tests

Prior to the World War, very few laboratories in this country were equipped with machines for testing the impact value of steels. When the United States began building aviation motors however, it was found advisable to include specifications for impact values for motor parts subjected to severe stresses, such as crankshafts and connecting rods. This branch of physical testing was found to be of such great value in determining whether parts had been properly heat treated or not, that impact testing is now used in a large number of manufacturing concerns as one of the means of controlling the quality of their product.

A symposium on the subject of impact testing of materials was recently held at Atlantic City and the writer would recommend the reading of the preprint of this symposium[5] to any one interested in the subject.

As stated in the preprint, the essential results obtained from impact tests is the amount of energy absorbed by a specimen in undergoing rupture or a certain deformation. The writer has always found that steels of a brittle nature will show low impact readings and crytalline fractures, while steels possessing considerable toughness will show high impact readings with fine grained fractures. The quality of a steel should never be judged from its impact value alone, however, for it is necessary to consider the static tensile properties, torsional strength, shearing strength, etc. along with the impact reading, to properly classify the material. A plain carbon steel will usually show a higher impact reading than an alloy steel, principally due to the lower hardness of the plain carbon steel. If the plain carbon steel is heat treated so as to possess the same tensile strength as the alloy steel, however, a lower impact reading will then be obtained on the plain carbon steel than will be found on the alloy steel. One cannot estimate the impact value of a steel from its static tensile properties for the impact test is a dynamic one, while the usual tensile test is of a static nature.

As to the value of the impact test, the writer can furnish records of tests made on heat treated alloy steel forgings where the tensile properties came well within specified limits but the impact values were so low that the parts were rejected. Service tests proved that such material was unfit for the severe duty to which the parts made from the same were subjected. The

5. Symposium on Impact Testing of Materials. American Society for Testing Materials—1922 Annual meeting.

fracture obtained on the tensile test specimens in such cases would show a fine grained structure but the impact fracture possessed a fairly coarse grained structure.

An examination of the literature on the subject of case hardening shows that notched bar tests on the various types of carburizing steels have never been conducted. As such information in the writer's opinion was of sufficient value to promote research work along these lines, Izod notched bar tests, commonly known as impact tests, were conducted on the following S.A.E. steels—1015, 1112, 2315, 3115 and 6120. Two bars of each grade of steel were used for these tests, one of the bars of each type of steel being received from a different source of supply than the other bar. The analysis of these bars of steel are shown in Table II.

The specimens were completely machined before treating, both because of the difficulty we would have experienced in grinding the notch and also because the carburizing of the completely machined test piece left the specimen in a state nearer to that of an actual carburized part. The compound used for carburizing the specimens was in a finely powdered state and and contained the following materials.

Sole Leather	25%
Barium Carbonate	25%
Hard Wood Charcoal	50%

A mixture of this type gives a higher carbon content at lower temperatures than the usual run of case hardening materials and is therefore particularly adapted for parts which must be carburized at low temperatures (1500-1600 degrees Fahr.).

Table II
Analysis of Steels Used for Izod Tests

	Chemical Composition in Per Cent							
Type of Steel	*Carbon*	*Mang.*	*Phos.*	*Sulphur*	*Silicon*	*Chrom.*	*Nickel*	*Vanadium*
S.A.E. 1015 (A)	.19	.42	.009	.036	.01	...	...	...
S.A.E. 1015 (S)	.20	.49	.011	.026	.01	...	...	...
S.A.E. 1112 (B)	.11	.75	.133	.088	..	...	...	...
S.A.E. 1112 (P)	.11	.67	.106	.085	..	...	...	...
S.A.E. 2315 (H)	.18	.61	.013	.041	.19	...	3.35	...
S.A.E. 2315 (N)	.18	.61	.017	.031	.10	...	3.52	...
S.A.E. 6120 (M)	.15	.60	.008	.035	.13	.97	...	.20
S.A.E. 6120 (C)	.15	.67	.029	.030	.18	1.03	...	.23
S.A.E. 3115 (E)	.19	.61	.020	.025	.18	.62	1.14	...
S.A.E. 3120 (Z)	.23	.58	.031	.033	.07	.69	1.32	...

The temperatures used for hardening the carburized Izod specimens are in accordance with the treatments recommended by the S.A.E. Iron and Steel Committee. Specimens carburized and single quenched were treated for the case only and not quenched from a temperature high enough to refine the core to any extent, inasmuch as such a treatment would leave the case in a slightly coarse condition. The latter practice is not as widely used as is treating for case refinement only.

Table III gives the results obtained from these notched bar tests as well as the hardness of the case and core. The depth of case was also measured on each of these specimens by examining the untreated end of each piece under the microscope. The S.A.E. 1015 steels and 1112 steels showed a case depth of from .023 to .025 inch, the alloy steels all possessing about a .030 inch case. It can thus be seen that the alloys promote carburization. It was

also interesting to note that 1015, 3115, and 3120 steels showed a large well defined network or envelope structure of cementite in the carburized state, the 1112 steels showing a slightly smaller grain size, the 2315 steels a small poorly defined network, while the 6120 steels showed practically no network structure. The photomicrographs of the case areas on the single treated specimens bring out this point to some extent.

The fractures on all of these specimens were carefully examined after

Table III

Izod Test Results

Steel	Heat treatment	Izod test in foot pounds	Case Hardness scleroscope	Core Hardness Brinell No.
S.A.E. No. 1015 (A)	Carburized and pot cooled; 1650-oil; 1440-water	2	90	157
S.A.E. No. 1015 (A)	Carburized and pot cooled; 1650-oil; 1410 water	2	90	151
S.A.E. No. 1015 (A)	Carburized and pot cooled; 1450-water	2	88	180
S.A.E. No. 1015 (A)	Carburized and oil quenched; 1650-oil; 1440-water	2	90	157
S.A.E. No. 1015 (A)	Carburized and oil quenched; 1450-water	3	..	166
S.A.E. No. 1015 (A)	Sand treated and pot cooled; 1650-oil; 1440-water	70	..	163
S.A.E. No. 1015 (A)	Sand treated and pot cooled; 1450-water	10	..	180
S.A.E. No. 1015 (A)	Sand treated and oil quenched; 1440-water	22	..	170
S.A.E. No. 1015 (S)	Carburized and pot cooled; 1650-oil; 1410-water	2	90	172
S.A.E. No. 1015 (S)	Carburized and pot cooled; 1430-water	2	91	196
S.A.E. No. 1015 (S)	Sand treated and pot cooled; 1650-oil; 1410-water	66	..	179
S.A.E. No. 1015 (S)	Sand treated and pot cooled; 1430-water	19	..	196
S.A.E. No. 1112 (B)	Carburized and pot cooled; 1650-oil; 1440-water	2	92	165
S.A.E. No. 1112 (B)	Carburized and pot cooled; 1450-water	1	91	180
S.A.E No. 1112 (P)	Sand treated and pot cooled; 1650-oil; 1410-water	29	..	153
S.A.E. No. 1112 (P)	Sand treated and pot cooled; 1430-water	8	..	167
S.A.E. No. 2315 (H)	Carburized and pot cooled; 1540-oil; 1400-oil	6	82	370
S.A.E. No. 2315 (H)	Carburized and pot cooled; 1540-oil; 1350-water	8	87	302
S.A.E. No. 2315 (H)	Carburized and pot cooled; 1370-water	3	87	329
S.A.E. No. 2315 (H)	Sand treated and pot cooled; 1540-oil; 1350-water	28	..	311
S.A.E. No. 2315 (H)	Sand treated and pot cooled; 1370-water	18	..	340
S.A.E. No. 2315 (N)	Carburized and pot cooled; 1540-oil; 1350-water	6	87	364
S.A.E. No. 2315 (N)	Carburized and pot cooled; 1370-water	2	84	387
S.A.E. No. 2315 (N)	Sand treated and pot cooled; 1540-oil; 1350-water	27	..	349

(Table III continued on next page)

Table III (Continued)
Izod Test Results

Steel	Heat treatment	Izod test in foot pounds	Case hardness scleroscope	Core hardness Brinell No.
S.A.E. No. 6120 (M)	Carburized and pot cooled; 1650-oil; 1475-water	10	92	265
S.A.E. No. 6120 (M)	Carburized and pot cooled; 1500-water	2	92	255
S.A.E. No. 6120 (M)	Sand treated and pot cooled; 1650-oil; 1475-water	37	..	265
S.A.E. No. 6120 (M)	Sand treated and pot cooled; 1500-water	23	..	252
S.A.E. No. 6120 (C)	Carburized and pot cooled; 1650-oil; 1475 water	11	92	295
S.A.E. No. 6120 (C)	Carburized and pot cooled; 1500-water	4	92	295
S.A.E. No. 3115 (E)	Carburized and pot cooled; 1575-oil; 1425-water	4	91	295
S.A.E. No. 3115 (E)	Carburized and pot cooled; 1440-water	2	92	349
S.A.E. No. 3115 (E)	Sand treated and pot cooled; 1575-oil; 1425-water	20	..	311
S.A.E. No. 3115 (E)	Sand treated and pot cooled; 1440-water	8	..	321
S.A.E. No. 3120 (Z)	Carburized and pot cooled; 1525-oil; 1425-water	2	91	477

Table III Notes

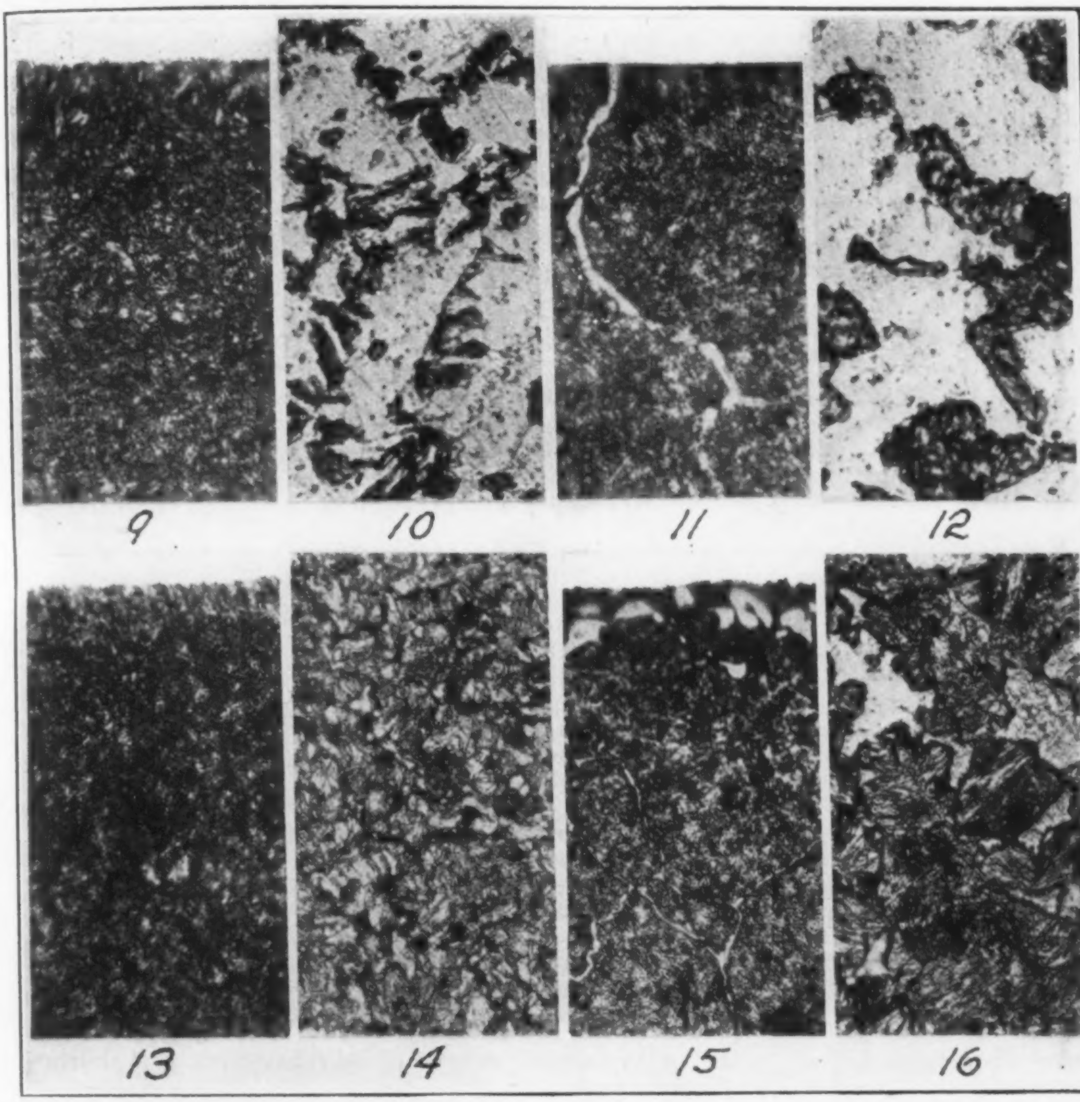
1—Temperatures are given in degrees Fahrenheit.
2—Samples were carburized by heating in a finely powdered form of case hardening compound for four hours at 1650 degrees Fahr.
3—Samples were sand treated by heating in sand for four hours at 1650 degrees Fahr.
4—Lead bath furnace used for treating the carburized specimens.
5—All samples drawn to 350 degrees Fahr. before testing.
6—Izod results represent the average of from three to six tests in every case.

being tested, the results being shown in table IV. From these fracture tests, it can be seen that all of the alloy steels possess a fine grained case and core after carburizing and double quenching, but show a crystalline core, with a fine grained case after carburizing and single quenching. The carburized 1015 steels show a slightly coarse grained case and coarse grained core after double treating, but after single quenching show a slightly coarse grained case with a very coarse core. The sand treated specimens of 1015 steel show a fine grained fracture after double quenching but a very coarse grained fracture after single quenching, and also after sand treating, quenching from pot, and single quenching.

The carburized samples of Bessemer screw stock (1112 steel) possess a coarse grained case and a very coarse grained core after double quenching as well as after single quenching. The specimens of 1112 steel that were sand treated also show a very coarse grained fracture both after double and single quenching. It can thus be seen that screw stock can not be refined by double quenching as can the other types of case hardening steels. Referring again to Table II, we obtain the following information as to impact values and hardness tests—

Izod Tests

The S.A.E. 1015 steels gave the highest impact readings of all the



CASE HARDENED SPECIMENS

S. A. E. 1112 Steel (B)

Fig. 9—Case structure on impact specimen double heat treated after carburizing. X 500. Fig. 10—Core structure on impact specimen, double heat treated after carburizing. X 500. Fig. 11—Case structure on impact specimen, single heat treated after carburizing. X 500. Fig. 12—Core structure on impact specimen, single heat treated after carburizing. X 500.

S. A. E. 3115 Steel (E)

Fig. 13—Case structure on impact specimen double heat treated after carburizing. X 500. Fig. 14—Core structure on impact specimen double heat treated after carburizing. X 500. Fig. 15—Case structure on impact specimen single heat treated after carburizing. X 500. Fig. 16—Core structure on impact specimen single heat treated after carburizing. X 500.

steels tested, when sand treated and double quenched. The high results obtained from this type of steel are due we believe to the softness of the material. This type of steel however does not show as high static tensile properties as do the alloy case hardening steels in the double treated condition. The high impact reading on the 1015 steels therefore is obtained at the sacrifice of its tensile strength. The 1112 steel, or Bessemer screw stock, showed an impact value of less than half that obtained on the 1015 steels, due to the high percentage of impurities present. The alloy steels showing the highest Izod readings when sand treated and double quenched were those of

the 6120 series the 2315 steel coming second, the S.A.E. 3115 steels showing the lowest impact readings. These 3 types of alloy case hardening steels all possess about the same static tensile properties if the carbon is approximately the same in each case.

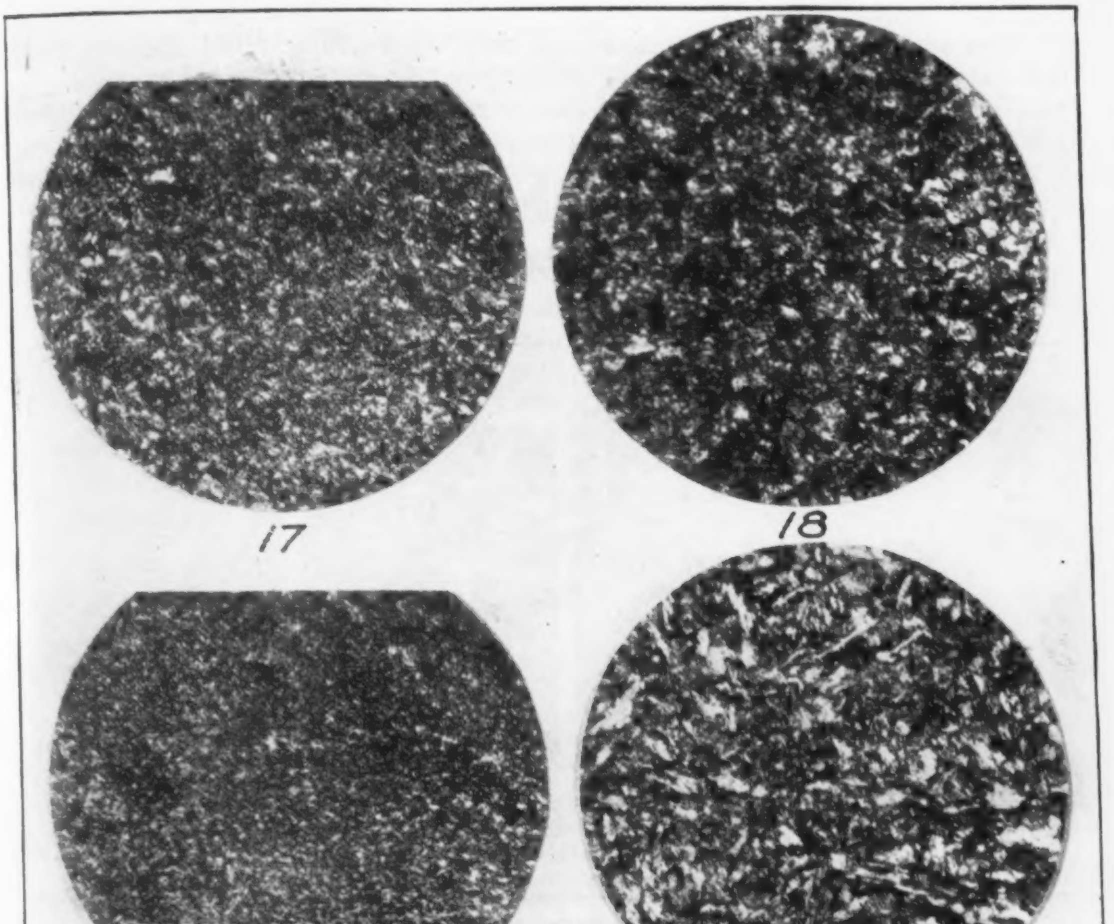
The values obtained on the different types of steels, sand treated and single quenched, were all considerably lower than those found on the specimens double treated. The 6120 steel gave the highest Izod reading in the

Table IV
Fractures on Izod Test Specimens

Steel	Treatment	Case refinement Grained structure	Core refinement Grained structure
S.A.E. 1015	Carburized and double quenched.	Slightly coarse	Coarse
S.A.E. 1015	Carburized and single quenched..	Slightly coarse	Very coarse
S.A.E. 1015	Sand treated and double quenched		Fine
S.A.E. 1015	Sand treated and single quenched		Very coarse
S.A.E. 1015	Sand treated, pot quenched, single quenched		Very coarse
S.A.E. 1112	Carburized and double quenched.	Coarse	Very coarse
S.A.E. 1112	Carburized and single quenched..	Coarse	Very coarse
S.A.E. 1112	Sand treated and double quenched		Very coarse
S.A.E. 1112	Sand treated and single quenched		Very coarse
S.A.E. 3115	Carburized and double quenched.	Fine	Fairly fine
S.A.E. 3115	Carburized and single quenched..	Fine but crystalline outer rim	Coarse
S.A.E. 3115	Sand treated and double quenched		Fairly fine
S.A.E. 3115	Sand treated and single quenched		Coarse
S.A.E. 2315	Carburized and double quenched.	Very fine	Fine
S.A.E. 2315	Carburized and single quenched..	Very fine but crystalline outer rim	Slightly coarse
S.A.E. 2315	Sand treated and double quenched		Fine
S.A.E. 2315	Sand treated and single quenched		Slightly coarse
S.A.E. 6120	Carburized and double quenched.	Fine velvety	Fine
S.A.E. 6120	Carburized and single quenched..	Fine	Coarse
S.A.E. 6120	Sand treated and double quenched		Fine
S.A.E. 6120	Sand treated and single quenched		Coarse

single treated condition, the other steels running as follows, from highest to lowest, 2315, 1015, 3115 and 1112.

The specimens of 1015 steel sand treated, quenched from the pot into oil and then single quenched showed only about 1/3 the strength of specimens sand treated, pot cooled and double quenched. A very coarse grained fracture was obtained on those samples that were pot quenched, for a long soaking above the critical temperature before quenching produces a coarse grained structure. Material given this treatment however possesses a slightly finer grained structure and higher Izod value than specimens pot cooled, then single quenched. One would expect the S.A.E 1015 steels, which showed such high impact readings in the sand treated condition, to show correspondingly high values when carburized and hardened for case and core refinement. We found however that these plain carbon steels showed a very low impact reading when carburized and double quenched (2 foot pounds) probably due to the brittleness of the case, as compared with the alloy steel cases. The core also showed a coarse grained structure as compared with the fine grained fracture obtained on the 1015 steel specimens that were sand treated and double quenched. The same Izod readings were obtained on the 1015 steel specimens single treated after carburizing as were found on the double treated carburized specimens, but the core was much coarser on the pieces

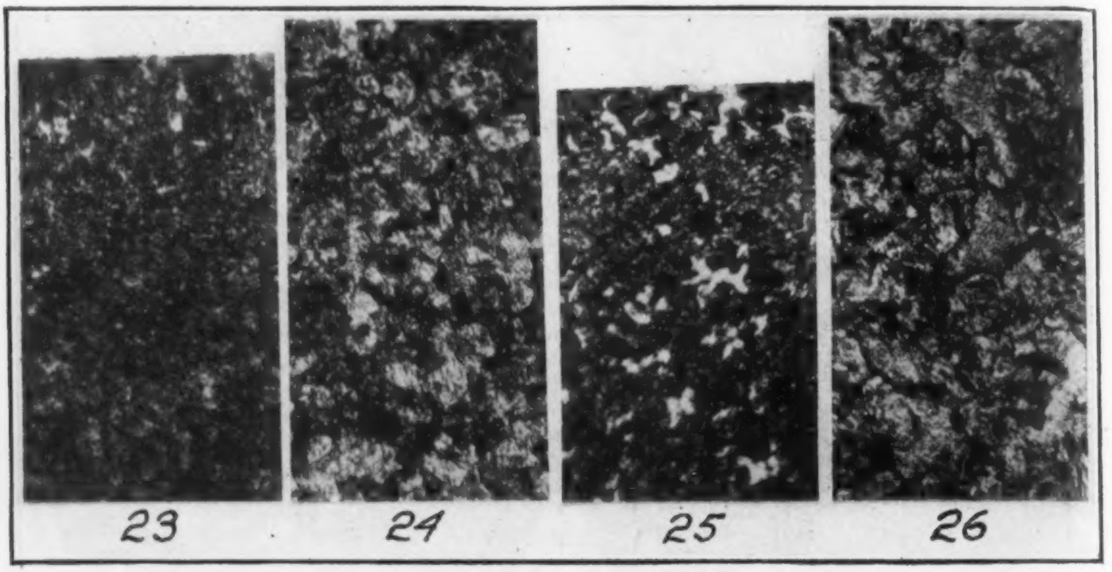


S. A. E. 2315 Steel (H)

Fig. 17—Case structure on impact specimen double quenched after carburizing, second quench being in oil. X 500. Fig. 18—Core structure on impact specimen double quenched after carburizing, second quench being in oil. X 500. Fig. 19—Case structure on impact specimen double quenched after carburizing, second quench being in water. X 500. Fig. 20—Core structure on impact specimen double quenched after carburizing, second quench being in water. X 500. Fig. 21—Case structure on impact specimen single quenched after carburizing. X 500. Fig. 22—Core structure on impact specimen single quenched after carburizing. X 500.

that were quenched for case refinement only. Quenching from the pot, then double and single treating also gave readings of from 2 to 3 foot pounds.

The S.A.E. 6120 steels in the carburized and double treated state gave the highest impact readings of any of the steels tested, the 2315 steels showing slightly lower values. As in the case of the sand treated specimens, the 3115 steel gave the lowest values in the carburized and double treated conditions of any of the alloy steels tested. The 3120 steel gave lower readings than the 3115 samples due to the greater core hardness produced by the higher carbon content of the 3120 steel. The 1015 and 1112 steels gave the



CASE HARDENED SPECIMENS
S. A. E. 6120 Steel (M)

Fig. 23—Case structure on impact specimen double heat treated after carburizing. X 500. Fig. 24—Core structure on impact specimen double heat treated after carburizing. X 500. Fig. 25—Core structure on impact specimen single heat treated after carburizing. X 500. Fig. 26—Core structure on impact specimen single heat treated after carburizing. X 500.

same low readings in the carburized and double quenched condition as was obtained by the 3120 steel specimens. As was the case in the sand treated specimens, the alloy steels single quenched after carburizing, showed lower Izod readings than when quenched for both core and case.

It may be interesting to note that in a test run some time ago by one of the large automobile concerns in Detroit, the following oil hardening gear steels, tested for impact values, came out as follows, from highest to lowest: 6150, 2350, 3250 and 3150. It is claimed by a well known authority on physical testing, that impact strength drops off very rapidly with a drop in temperature. One would thus expect a greater failure of parts subjected to shock when exposed to cold weather.

Hardness Tests

The Brinell hardness tests on the core of the plain carbon steels showed much lower readings than the values obtained on the alloy steels. With the exception of the 6120 steels, all of the specimens from the different types of steels, single quenched after carburizing or sand treating, showed higher Brinell readings than samples double treated after carburizing. It is also interesting to note the effect of 4 points difference in carbon on the hardness of the core of the chrome-nickel series. As a similar relation is to be expected from a variation in carbon on the 2315 and 6120 steels, one can thus see the necessity of obtaining material within a close carbon range if the sections

to be carburized are small and toughness is an important factor.

The case scleroscope readings showed about the same on all of the samples, with the exception of the 2315 series, where slightly lower readings were obtained. These 3½ per cent nickel steel specimens were also the only ones that were not file hard to the Nicholson flat temper testing file, when in the carburized and hardened state.

Photomicrographs

Figs. 4 through 26 show photomicrographs of the case and core of the different types of steel after carburizing and double treating as well as after single quenching for case refinement only. The case on all of the steels after double quenching show a fairly fine grained martensitic structure, with ce-

Table V
Static Tension Tests

Steel	Heat treatment	Tensile strength in pounds per square inch	Elongation in 2 inches Per cent	Reduction of area Per cent	Brinell hardness
S.A.E. 1015	Heated in sand for 4 hours at 1650 degrees Fahr. and cooled in pot. Reheated to 1650 degrees Fahr. and oil quenched. Reheated to 1400 degrees Fahr. and water quenched....	103,100	11.5	26.5	192
S.A.E 1015	Sand treated as above. Reheated to 1450 degrees Fahr and water quenched	127,500	4.8	5.5	223
S.A.E. 6120	Sand treated as above. Reheated to 1650 degrees Fahr. and oil quenched. Reheated to 1450 degrees Fahr. and water quenched	125,500	17.0	35.4	241
S.A.E. 6120	Sand treated as above. Reheated to 1490 degrees Fahr. and water quenched...	137,800	13.1	30.0	255

Analysis of Steels Used for Above Tests

	S.A.E. 1015 Per cent	S.A.E. 6120 Per cent
Carbon	.18	.14
Manganese	.31	.68
Phosphorus	.021	.008
Sulphur	.041	.024
Chromium	..	1.03
Vanadium	..	.15

mentie in the globular form and well distributed throughout the section. A trace of the network structure of cementite is found however in the case areas of specimens single quenched after carburizing, for the temperature used for refining the case only was not high enough to entirely break up the coarse grained structure produced in the carburizing operation. The 6120 steels are the exception to the above for practically no network was present after carburizing and before hardening. This network of cementite is quite often the cause of grinding cracks and spalling of the case, so it is highly desirable to break up this network structure by properly carburizing and hardening the steel. Quenching from the pot and single quenching, while not refining the grain as well as double treating after carburizing, does have

the advantage of preventing the formation of this coarse grained network structure of cementite.

The core structures on all of the impact specimens, double quenched after carburizing, show a much finer grain than when single quenched, with the exception of the samples of Bessemer screw stock or 1112 steel, which showed a large coarse grained structure both after double and single quenching.

Tensile Tests

Static tension tests were conducted on specimens made of 1015 and 6120 steels, sand treated, then double and single quenched. The results given in Table V indicate that the higher tensile strengths obtained on specimens single quenched after carburizing are gained at the expense of the ductility of the material, especially in the case of the 1015 steel. The fractures obtained on the specimens of 1015 steel in the double treated state showed a fine grained structure but the specimens single quenched showed a very coarse grained fracture. Not so much difference was noted in the fractures of the 6120 steel specimens after double and single quenching, only a slight coarsely grained structure but the specimens single quenched showed a very coarse grained single treating being obtained on the specimens of this type of steel after single treating.

In conclusion, the writer trusts that this paper may arouse sufficient discussion to result in the publication of several more articles along similar lines, for such information should be of considerable value to all interested in the subject of case hardening.

LATHE BREAKDOWN TESTS OF SOME MODERN HIGH SPEED TOOL STEELS

By H. J. French and Jerome Strauss

Technical Abstract

This report is concerned with comparisons of performance of modern high speed tool steels in so-called "lathe breakdown tests," in which the endurance of tools is measured under definite working conditions, and likewise with the limitations of this method when applied to the purchase of steel. The modern steels are first classified according to chemical composition and this division made use of in discussion of results obtained.

Important features developed or conclusions drawn may be summarized as follows:

1. *Breakdown tests are not satisfactory as the basis of purchase for high speed tool steels.*
2. *While competitive comparisons of brands of nearly similar performance are not justified, owing to the qualitative nature of this type of test, relatively large differences may be ascertained with certainty providing suffient tools are tested and averages of at least* 2 *grinds are used in the interpretation of results.*
3. *In certain severe breakdown tests with roughing tools on* 3 *per cent nickel steel forgings, in which high frictional temperatures were produced, it was found that the performance of commercial low-tungsten high-vanadium and cobalt steel was superior to that of the high-tungsten low-vanadium type and special steel containing about* 1/4 *per cent uranium or* 3/4 *per cent molybdenum. The average power consumption in all cases was practically the same so that this factor need not be introduced in comparisons which may be made on the basis of endurance of the tools.*
4. *Modification in test conditions including small changes in tool angles but principally changes in cutting speed more markedly affected the performance of steel containing cobalt or special elements such as uranium or molybdenum than that of the basic types (plain chromium-tungsten-vanadium steels).*
5. *The relatively poor endurance of the high tungsten steels under severe working conditions was not observed in more moderate tests, made on the same test log with equal cutting speed and depth of cut but with reduced feed, in which the frictional temperatures produced were not so high. Also in these latter tests the performance of the cobalt steels was better than either the low or high tungsten steels.*
6. *Hardness determinations and examination of fractures*

A paper to be presented before the Detroit Convention October 2-7. The authors H. J. French is physicist, United States Bureau of Standards and Jerome Strauss, is chief chemist, United States Naval Gun Factory.

indicate that the various types of commercial high speed steel show differences in behavior under heat treatment and in physical properties which probably are of importance under moderate working conditions, and might counterbalance slight advantages in performance.

Introduction

UNLIKE structural steels, which are generally sold within definite limits of chemical composition, most carbon and practically all alloy tool steels are supplied as brands or under trade names. There are some advantages to this system, both from the standpoint of manufacturer and purchaser, but it has seriously retarded general dissemination of knowledge concerning different types and in many instances has been responsible for erroneous impressions regarding their properties and applications. This applies generally to tool steels but in particular to that important class termed "rapid" of "high speed" steels with which the authors are alone concerned in this report.

It has long been recognized that high grade raw materials, good melting practice and great care in fabrication, all based on an intimate knowledge of the product, are necessary in the manufacture of high speed tool steels and that variations in the many operations involved, which are closely related to tool performance, may readily overshadow the effects of small differences in chemical composition. However, this condition has frequently been misrepresented with the result that the importance of chemical requirements has been largely disregarded by purchasers.

In quite a few instances large consumers have selected brands on the basis of performance in so-called "breakdown tests" in which the endurance of tools is measured under fixed working conditions though the selling price and power consumption of the various steels may be introduced in any comparisons which are made. In recent years tests of this type have also been used in comparing the performance of special steels or in determining the effects of variations in heat treatment, despite the fact that Taylor[1] specifically recommended determining the cutting speed which would produce failure in 20 minutes under otherwise fixed working conditions and described at great length the reasons for following such a procedure. Comparison of the breakdown and Taylor tests is not within the scope of this report. The former is accepted because it has found commercial application and a portion of the work described in subsequent paragraphs may be characterized as a critical survey of this method of test. The cutting speeds, feed, depth of cut and general test conditions approximated those used in a number of cases for the purchase of large quantities of steel.

In studying the results first obtained, marked superiority in performance of certain types of steel was observed so that these alloys are first grouped according to chemical composition and the resulting classification is used in discussion of results of the lathe cutting tests. It is based upon the analysis of about 65 lots representing nearly 40 brands produced throughout the period 1919-1922[2].

Five sets of breakdown tests are described. The first three, which were

1. F. W. Taylor: On the Art of Cutting Metals. *Trans.* A. S. M. E., 1906.

2. Approximately ⅓ of all analyses was made by H. Bright, Assoc. Chemist, Bureau of Standards, ⅓ by chemists associated with one of the authors and the remainder collected from various other sources.

carried out at high speed with heavy cut and feed, cover comparisons of about 25 brands and are presented to show some of the limitations in test methods which have been used in the purchase of high speed tool steels. Test series No. 4 was carried out with reduced feed in order to ascertain whether the superior endurance observed for certain groups in the first three sets of tests was maintained under more moderate working conditions in which lower frictional temperatures were produced.

The expense of large tool tests, time, labor and special equipment required, made it desirable to carry out test No. 5 to determine whether comparable results could be obtained with small tools. Results of fracture tests, miscroscopic examination and secondary hardness determinations are also included to throw light upon the quality of metal tested or the characteristics of the various steels under heat treatment.

Previous Investigations

No attempt will be made to review the very large number of publications which have appeared since the discovery of the unique and remarkable properties of high speed tool steels and the presentation of a report by Taylor and White[3] which has since been characterized as the most important single metallurgical contribution made in the United States. Much of this more recent information does not have a very direct bearing upon the phases which will be considered while results of cutting tests of different brands or steels which have appeared from time to time either do not represent the best of the current types or are not strictly comparable on account of differences in material cut, angles, shape and size of tools, etc. Such data as may be introduced to advantage will be referred to in connection with the several features emphasized in subsequent paragraphs but no selected list of references is appended as a fairly complete bibliography on high speed tool steels has been prepared by one of the Engineering Libraries for the National Research Council and is now in preparation for publication.

Classification of Modern High Speed Tool Steels

While the essential alloying elements in high speed tool steels are chromium and tungsten practically all brands now produced in this country for roughing tools contain between 0.5 to 2.25 per cent vanadium. The term ***modern*** high speed tool steels therefore refers to chromium-tungsten-vanadium steels (which may or may not contain additional special elements) and little or no attention will be paid to the very few brands still manufactured without the intentional addition of vanadium, particularly as they are inferior in performance to the former types.

The modern steels may be grouped under 5 headings, as follows:

1. Low tungsten steels
2. Medium tungsten steels
3. High tungsten-low vanadium steels
4. Cobalt steels
5. Steels containing one or more special elements such as molybdenum or uranium and called "special steels"

Their relative importance from the standpoint of number of brands within each group and limits of chemical composition are indicated in Tables I, II and III which are based on results of analysis of one or more lots of 39 brands.

3. F. W. Taylor: On the Art of Cutting Metals. *Trans.* A. S. M. E., 1906.

Table I

Summary of Composition of 39 Brands of Modern High Speed Tool Steels Based on Analysis of 66 Lots

Type of High Speed Tool Steel	No. of lots analyzed	No. of brands found in specified type	Carbon, per cent Min.	Max.	Av.	Chromium, per cent Min.	Max.	Av.	Tungsten, per cent Min.	Max.	Av.	Vanadium, per cent Min.	Max.	Av.	Cobalt, per cent Min.	Max.	Av.	Mo, Per cent	U, Per cent
1. Low tungsten—high vanadium	10	6	.56	.74	.65	2.21	4.45	3.69	11.10	14.00	13.07	.50	2.15	1.47	...	...	...	...	..
2. Medium tungsten	4	2	.62	.71	.66	3.01	4.67	3.93	14.08	15.79	14.92	.69	2.07	1.54	...	...	...	...	..
3. High tungsten—low vanadium	36	22	.45	.85	.66	2.26	4.70	3.54	16.13	19.65	17.90	.48	1.24	.88	...	...	...	...	..
4. Cobalt	8	7	.58	.88	.69	2.78	4.31	3.70	13.07	18.79	16.38	.91	1.63	1.21	1.86	4.73	3.28	...	..
5. Special	8	7	..	..	..						(Typical	Compositions)							
(a) Molybdenum steels......	..	..	..	..	.69	...	...	3.52	....	....	12.88	..	...	1.97	...	...	...	.71	..
	..	..	..	..	.64	...	...	3.58	....	....	16.65	..	...	1.10	...	...	...	.71	..
	..	..	..	..	.60	...	...	4.00	....	....	15.50	..	...	1.20	...	...	...	.50	..
(b) Cobalt-molybdenum steels	..	..	..	..	.65	...	...	4.25	....	....	17.70	..	...	1.00	...	...	4.88	1.07	..
(c). Uranium steels	..	..	..	..	.66	...	...	3.94	....	....	13.80	..	...	1.45	...	...	...	...	.23
	..	..	..	..	.58	...	...	3.85	....	....	13.64	..	...	1.36	...	...	...	...	.19
	..	..	..	..	.64	...	...	3.21	....	....	17.03	..	...	.86	...	...	...	...	.26
	..	..	..	..	.80	...	...	3.63	....	....	19.80	..	...	.80	...	...	...	...	.21
Totals	66	44	..	..	..	...	...	...	....	....	....	..	...	...	...	...	...	...	..

About half of these are of the third type or so-called high tungsten-low vanadium steels. The low tungsten type, cobalt steels and those containing special elements such as molybdenum or uranium are about equally represented but, together, do not exceed the number of high tungsten steels. A medium tungsten-low vanadium steel is regularly manufactured in England[4]

Table II

Proportions of Manganese, Phosphorus, Sulphur and Silicon Found in 66 Lots of Modern High Speed Tool Steels Representing 39 Brands

Type of High Speed Tool Steel	Manganese per cent			Phosphorus per cent			Sulphur per cent			Silicon per cent		
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
All types.	.09	.43	.26	.004	.051	.023	.009	.061	.027	.09	.81*	.27

*Only one lot contained more than 0.51 per cent silicon.

Table III

Chemical Compositions of Cobalt High Speed Tool Steels (Produced in the United States)

Class of Steel	Brand	—Chemical C	Composition— Cr	W	V	Co	——Per cent—— Mn	P	S	Si
(a) Low tungsten—low cobalt..	A	.68	3.96	13.07	1.63	1.86	.19	.018	.021	.37
(b) Low tungsten—high cobalt..	B	.67	3.72	13.50	1.28	4.23	.42	.023	.023	.39
	B	.76	3.41	14.01	1.60	4.73	.34	.029	.061	.27
(c) High tungsten—low cobalt..	C	.66	3.45	17.80	1.06	2.54	.20	.022	.019	.45
	D	.88	4.29	18.79	1.30	2.92	..	...	...	.10
*(d) High tungsten—high cobalt..	E	.58	2.78	17.56	.93	3.35	.09	.016	.026	.18
	E	.72	3.26	18.40	.86	3.10	.08	.020	.017	.11
	F	.59	4.31	18.58	.91	3.34	.17	.024	.016	.10
	G	.68	3.68	17.51	.97	3.27	.30	.014	.010	.22

Table IV

Proportions of Carbon Found in 66 Lots of Modern High Speed Tool Steels Representing 39 Brands

Carbon range*	No. of steels in given limits	Proportion of total number of steels in given limits	
0.45 to 0.50....................	1	1.5	
0.50 to 0.55....................	1	1.5	
0.55 to 0.60....................	6	9.1	} 86.3
0.60 to 0.65....................	22	33.3	
0.65 to 0.70....................	22	33.3	
0.70 to 0.75....................	7	10.6	
0.75 and over..................	7	10.6	
	66	99.9	

* Minimum value observed 0.45 per cent carbon.
* Maximum value observed 0.88 per cent carbon.

but evidently a similar product is of minor importance in the United States as only two examples were found in the samples analyzed and one of these contained high vanadium which is characteristic of a low tungsten steel. In addition, different lots of both brands were found within the limits of classes 1 or 3 (Table I) so that the medium tungsten steels may be considered largely as "off-heats" and the least important of the first three groups comprising "basic types".

4. T. H. Nelson: Comparison of American and English Methods of Producing High Grade Crucible Steels. *Raw Material*, 4, No. 12, p. 424.

Compositions of Various Types

There is no marked difference in the proportions of carbon, manganese silicon or chromium found in the different groups. In fact the average values for carbon and chromium shown in Table I are very nearly the same and much closer than might ordinarily be expected from any such survey as the one under consideration. The principal differences are, therefore, in the proportions of tungsten and vanadium present and whether cobalt or some such special elements as molybdenum or uranium have been introduced.

Table V

Proportions of Chromium Found in 66 Lots of Modern High Speed Tool Steels Representing 39 Brands

Proportions of Chromium* per cent	No. of steels in given limits	Proportion of total number of steels in given limits, per cent		
2.00 to 2.50	2	3.0		
2.50 to 3.00	3	4.5		
3.00 to 3.50	18	27.3	—65.2	86.4
3.50 to 4.00	25	37.9		
4.00 to 4.50	14	21.2		
4.50 to 5.00	4	6.1		
	66	100.0		

* Minimum value observed 2.21 per cent Cr.
* Maximum value observed 4.70 per cent Cr.

The three basic types, referred to previously as the low tungsten, medium tungsten and high tungsten varieties, are often called respectively 13, 15 and 18 per cent tungsten steels and examination of Table I will show that these values are practically identical with the averages obtained in the present survey. The best known brands of the first type contain about 1.75 to 2.25 per cent of vanadium but there appears to be a second group in which lower proportions of this element, between about 0.75 and 1.25 per cent, are found. The so-called 18 per cent tungsten steels usually contain about 0.50 to 1.25 per cent vanadium.

The alloys of group 4, which are regularly produced by a number of manufacturers and therefore not included in the special steels of group 5 may be subdivided into the following:

a. Low tungsten-low cobalt steels
b. Low tungsten-high cobalt steels
c. High tungsten-low cobalt steels
d. High tungsten-high cobalt steels

It is to be noted that these steels fall naturally into groups representing basic types to which varying proportions of cobalt, between about 2 and 5 per cent, have been added. However, the vanadium is generally found to be near the average values or low limits shown in Table I. A similar subdivision can be made for the special steels (Table I) containing either molybdenum or uranium but since, for the most part, they are not yet of very great industrial importance and can in some cases at least be characterized as experimental heats, no additional comments concerning their compositions need be added.

The average carbon content of all major groups is between 0.65 and 0.70

per cent but variations ordinarily encountered are between 0.55 and 0.75 per cent. At times even higher proportions of carbon are found but there is a decided tendency to keep this element above the specified low limit (0.55 per cent) as shown in Table IV.

There appears to be a general tendency on the part of most manufacturers to keep the manganese content of all steels below about 0.25 per cent but larger proportions are frequently found. This element, and carbon also, tend to increase the hardness of high speed tool steels but at the same time they make the tools more brittle. It was for this reason that Taylor recommended the manganese content be limited to about 0.15 per cent.

With respect to the effect of silicon in high speed tool steels Taylor reported:—"The statement has been published several times that high silicon tended toward higher cutting speeds in high speed tools. In developing our patent, we experimented quite thoroughly with this element and arrived at the conclusion that high silicon tended toward slower cutting speeds, particularly when cutting the harder metals. In our patent, therefore, we recommended the low silicon, 0.15 per cent".

It is interesting to note that the average silicon content found in 66 lots of the modern steels is almost twice the value specified and that a fair maximum for this element would be about 0.45 per cent although one brand contained as much as 0.8 per cent.

The high limits of phosphorus and sulphur are somewhat greater in these alloys than those ordinarily specified for structural steels and considerably in excess of proportions usually present in tool steels other than high speed. Taylor found that high phosphorus and sulphur "were much less injurious to high speed tools than they were to carbon tools" but claimed they still exerted a harmful influence and because of the high cost of production for the former, resulting from necessarily large additions of expensive alloying elements, recommended that only irons low in phosphorus and sulphur be used in their manufacture. The present general tendency, as regards chemical composition, seems to include an increase in the permissible proportions of those elements, which may be termed impurities, over amounts originally recommended by Taylor. However, certain brands will repeatedly contain higher proportions of manganese, silicon, phosphorus or sulphur than others of the same type, a natural result of differences in raw materials and mill practice.

As previously stated, no marked differences in chromium are observed between different groups. More than half of all samples analyzed contain between 3 and 4 per cent while the proportions present in over 85 per cent of these steels is between 3 and 4.5 per cent (Table V). There are, of course, variations outside the specified limits and certain brands may be considered to contain somewhat higher or lower chromium than others but the majority of steels are within fairly close limits with respect to this element. The chromium in the modern steels is also lower than that in the best of Taylor's steels and in this respect both English and American products are similar. However, the latter contain generally higher vanadium as is shown in Table VI.

The observed uniformity in chemical composition of steels containing large proportions of special elements is worthy of attention as is also the fact that so many brands produced under widely different manufacturing conditions fall into such few groups. This condition must be considered as recognition of the importance of the chemical composition of high speed tool steels,

not alone as a single class within general limits, but from the standpoint of the different types in this class. It is therefore patent to examine the results of cutting tests of modern steels with the view of comparing types as well as brands and both methods will be used in interpretation of the test

Table

Compositions of American and
(Cobalt and Special

Type of Steel	Commonly called	Produced in	Carbon	Manganese
Low tungsten	13% Tungsten steel "Twist Drill"	United States	.60/.75	.10/.45
		England*	.50/.70	.20 max.
Medium tungsten	15% Tungsten steel "Standard"	United States	.60/.75	.10/.45
		England*	.55/.65	.20 max.
High tungsten	18% Tungsten steel "Super"	United States	.55/.75	.10/.45
		England*	.55/.65	.20 max.

*These limits obtained from T. H. Nelson: Comparison of American and English Methods of Producing
†Sometimes up to 20 per cent.

data which follow. It might be well, at this point, to call attention to the fact that metallurgists have often taken exception to the classification of commercial high speed tool steels according to chemical composition, particularly when the tungsten content is made the basis of division. This is because the combined effects of small variations in the other elements present and differences in methods of production or treatment might affect the performance to as great a degree as changes in the proportions of tungsten. Despite such variations the majority of steels tested showed performance generally characteristic of the group in which they were placed so that the chemical classification made and its application to discussion of the cutting tests appears justifiable.

Severe Breakdown Tests of 1″ x ½″ Roughing Type of Lathe Tool

Description of Tests

In tables XI and XII are given results of three series of cutting tests made with 1 x ½-inch lathe tools prepared from about 25 brands and these are grouped according to the type compositions previously described. The first two were carried out in different shops with slightly different tool angles and cutting speeds as shown in Table VII but with tools made from the same bars of any single brand. Heat treatments used in both series were carried out at one time with the same equipment and operators under the instructions of the manufacturers' representatives.

The third set of tests consisted of some of the tools in the first series after they had been thoroughly annealed, re-treated and ground, together with tools from different lots of the same brands or types not originally represented. Annealing was carried out by heating to 1550 degrees Fahr. and slowly cooling in a furnace to room temperature while the final heat treatments were not necessarily those recommended by the manufacturer but were chosen with the idea of obtaining the best tool performance for each type. These treatments were carried out by different operators in two shops which had not participated in tests Nos. 1 and 2. Thus the three sets of tests should furnish a definite idea regarding the possibility of reproducing results in a severe breakdown test with roughing tools, particularly with respect to brand or type comparisons.

Tool Form

The form of tool selected for all tests was that known as Sellers No. 30

and is commonly employed for heavy duty roughing work. Its angles are 6-degree clearance, 8-degree back slope and 14-degree side slope, while the radius of the nose was made 3/16 inch. The edge of the tool between this arc and its full width was straight and met the surface of the bar about 1 inch

VI

English High Speed Tool Steels.
Steels not included.)

Phosphorus	Sulphur	Silicon	Chromium	Tungsten	Vanadium
——Usual Limits of Chemical Composition Per Cent——					
Max. .050	Max. .060	.10/.45	3.25/4.25	11.00/14.00	1.75/2.25 or .50/1.25
low as possible		trace	2.50/3.00	12.00/14.00	Nil to trace
Max. .050	Max. .060	.10/.45	3.25/4.50	14.00/16.00	.50/2.25
low as possible		trace	2.75/3.50	14.00/16.00	Nil to .50
Max. .050	Max. .060	.10/.45	3.00/4.50	16.00/19.50†	.50/1.25
low as possible		trace	3.00/4.00	16.00/18.00†	.50/1.00

High Grade Crucible Steels. Raw Material, 4, No. 12, p. 424.

from the end. This form was adhered to in tests Nos. 2 and 3 but in test No. 1 the angles were accidently modified to 6-degree clearance, 7½-degree back slope and 12-degree side slope.

Heat Treatment

After grinding roughly to the described form the tools were warmed on top or in front of the preheating furnace to about 300 degrees Fahr. preheated in semi-muffle or muffle type furnaces, subsequently heated to the quenching temperature and quenched in either sperm or Houghton's No. 2 soluble quenching oil. They were then tempered at temperatures shown in Tables XI and XII.

The tools were next carefully ground wet in an automatic machine in order thay they would all be of the same form. In addition to grinding the nose, top and bottom surfaces were ground on those tools tested in the third series. This was made necessary on account of slight distortion which resulted from hardening the entire length so that both ends of each bar could be tested, instead of heating only one end as was the case with tools used in tests Nos. 1 and 2. High heat furnace temperatures were controlled by platinum thermocouples connected to potentiometers while base metal couples and either direct reading galvanometers calibrated just prior to test or potentiometers were used in maintaining preheating and tempering temperatures. For the few tools subjected to very low-temperature tempering calibrated thermometers were used. Preheating was carried out in semi-muffle type furnaces except for a few tools used in test No. 3 when electrically heated muffles were used.

The time for which tools were held in the high heat furnace was carefully controlled in all cases. The relatively large variations and generally longer periods in test No. 3 were due principally to the use of several furnaces of varying size and construction necessitated by breakdown of the first unit. The "sweating operation" in the hardening of high speed tool steels is a most important feature and the rapidity with which the desired effect can be produced for steel of nearly constant mass depends largely on the heating units. If the steel is held too long at high temperatures in the neighborhood of or above 2400 degrees Fahr. excessive oxidation and considerable decarburization result and in addition the metal becomes "mushy" so that it readily breaks when squeezed by tongs (Fig. 1). The time for which tools were held in the high heat furnace was therefore longer in those cases in

which units of relatively small thermal capacity were employed but in making use of any furnace preliminary tests were first made to determine what was considered to be the proper time of heating.

For tests Nos. 1 and 2 oil fired semi-muffle furnaces were employed while a similar type, heated by gas, or a carbon plate resistance furnace was used in hardening tools tested in the third series.

Test Procedure

Heavy duty motor-driven engine lathes, of a capacity somewhat in excess of that actually required for the work to be performed, were used in all

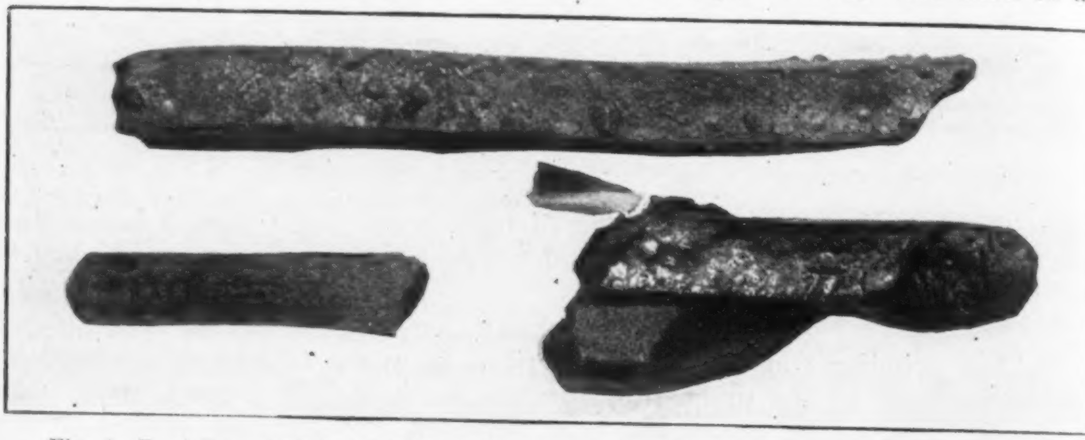


Fig. 1—Partially melted tool left too long in the high heat furnace at 2415 degrees Fahr. Tool broke where held by tongs in attempting to remove it from furnace.

tests. That employed in tests Nos. 1 and 3 is shown in Fig. 2. Speed control of the motor was such as to permit obtaining the desired surface speed of the test log within about +5 and —0 per cent and all tests were run dry.

Table VII
Conditions Under Which 1 x ½-inch Lathe Tools Were Tested

Test Series	1	2	3
Desired cutting speed, feet per minute at bottom of cut	67	61	60
Feed, inches per rev	.045	.045	.045
Depth of cut, inches	3/16	3/16	3/16
Tool angles—			
Clearance	6	6	6
Back slope	7½	8	6
Side slope	12	14	8
Nose	3/16" radius	3/16" radius	3/16" radius
Test logs used	I and II	III	II
(Refer to Table VIII for properties)			

The tools varied in length from 8 to 11 inches and the holder in which they were used was 15 inches long. This consisted of 2 carefully machined U shaped sections with the bottom of the groove square, 17/32 inch wide and 3/8 inch deep; one section was placed above and the other below the tool and both were held in alignment by two dowel pins at each end. The holder with the tool in place was clamped in the four-bolt tool post shown in Fig. 2.

Cutting was done on test logs of about 15 inches diameter and 8 feet long, of forged and heat treated 3 per cent nickel steel such as is in wide commercial use for heavy forgings. One to two inches was removed from

the diameter after heat treatment and testing was stopped when the log had been cut down to 8 inches. The chemical and physical characteristics of these forgings are shown in Table VIII.

It will be noted that the test logs used in the 3 series of tests are quite

Table VIII

Properties of Test Logs Used

Log No.	I		II		III
Chemical composition, per cent—					
C	.34		.37		.30/.40
Mn	.59		.62		.50/.80
P	.043		.046		.05 max.
S	.034		.027		.05 max.
Si	.22		.12		......
Ni	2.88		2.93		2.50/3.50
Cr	.02		.03		......
Cu	.29		.32		......
Tensile properties obtained on "transverse specimens"	End 1	End 2	End 1	End 2	
Prop. limit, lb./sq. in.	63,100	66,200	63,100	65,100	70,000
Tensile Str. lb./sq. in.	98,900	98,300	97,200	100,300	110,000
Elong. per cent in 2 in.	17.3	17.5	13.5	15.0	18.0
Red area, per cent	24.0	23.2	17.9	22.6	31.0
Brinell hardness	196	196	202	207	215

Table IX

Comparison of Performance of Various Brands of High Speed Steels Based on Data Given in Table XI

(Ten steels selected at random from those tested)

	Average time of cut in minutes		Position in list		
Brand	1st set of tests speed: 67 ft. per min.	2nd set of tests speed: 61 ft per min.	1st set of tests	2nd set of tests	Type steel
B	10.06	10.32	1	3	Low W
C	8.80	11.68	2	2	Low W
O	7.87	7.36	3	6	High W
S	7.60	14.56	4	1	Cobalt
T	6.18	8.92	5	5	Special (Mo)
Q	5.52	9.41	6	4	Cobalt
H	4.90	6.15	7	9	High W
R	4.85	7.25	8	7	Cobalt
W	4.14	6.39	9	8	Special (U)
F	4.01	4.87	10	10	High W

similar and uniform throughout, as far as may be judged by the tensile properties and hardness. Without doubt, however, variations in machinability exist, so that one tool of each brand was tested before the second tools were used. The latter were then tested in order before the third tool of each brand was tried. Such regulation of the sequence of testing almost certainly renders physical variations in the test logs negligible in their effect upon results obtained. At least this procedure goes as far toward obtaining uniformity in large masses of metal as can reasonably be expected. The feed used in all tests was 0.045 inch per revolution and the depth of cut 3/16 inch; the desired cutting speed, determined on the bottom of cut, was 67 feet per minute in test No. 1, 61 feet per minute in No. 2 and 60 feet per minute in test No. 3 (See Table VII).

Before starting any test, great care was taken to remove the glazed

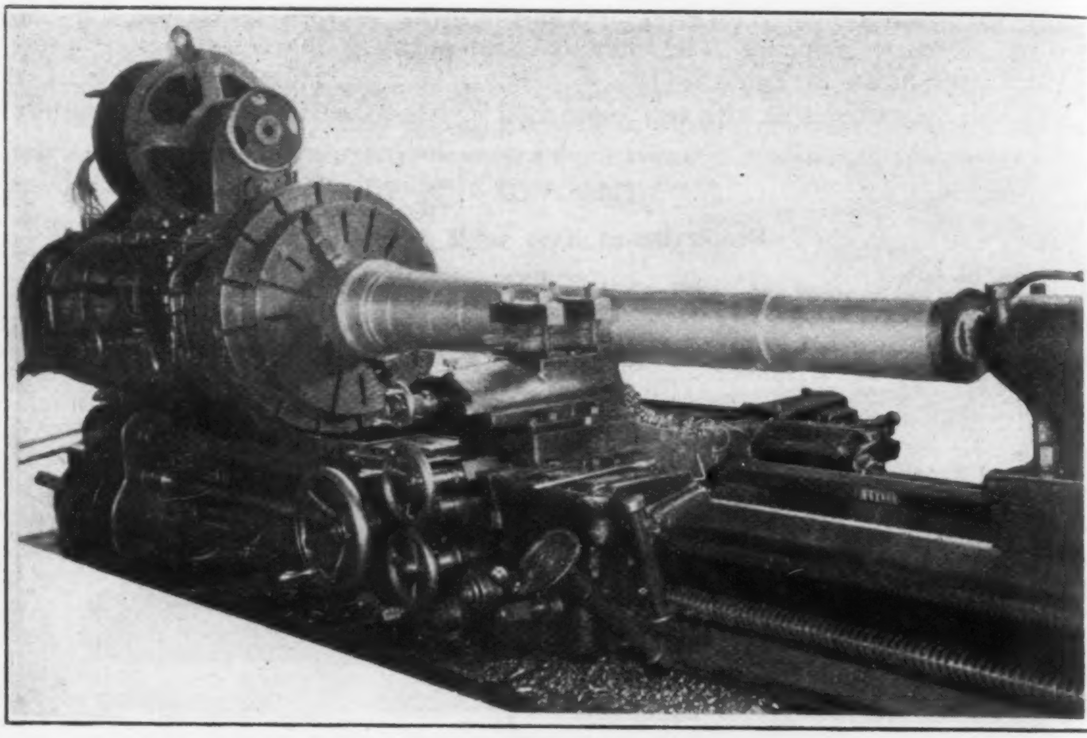


Fig. 2—Type of lathe and tool holder used in the cutting tests described.

surface of the log remaining after the breakdown of the previous tool and also any particles of the tool which may have been ground into the surface of the metal being cut. The tool to be tested was then forced against one side of the U shaped grooves in the holder and set to project beyond the end of it by 3/4 inch. The holder was next clamped in the tool post so that the side of the tool was at right angles to the log surface, the top level and the end of the nose on dead center. After adjusting the speed of the lathe

Table X

Comparison of Performance of Various Types of High Speed Tool Steels in Three Series of Lathe Tests.*

	Performance, as per cent of best type				
Group or steel	1st series	2nd series	3rd series	Total	Average
Low tungsten steels	100	94.1	100	294.1	98
Cobalt steels	67.8	100	97.3	265.1	88
High tungsten steels	56.3	55.3	64.2	175.8	59
			(uranium)		
Special steels (Mo or U added)	54.6	69.0	51.7	175.3	58
Medium tungsten steels	54.1	55.8	62.4	172.3	57
Special cobalt-molybdenum steel	...	...	84	....	..
Tungsten-less steel	44.4	...	17.7	62.1	31

* Details of tests given in Tables VII, VIII, XI and XII.

to give the desired surface speed to the log, the tool was fed in by hand (having previously been adjusted to proper depth) until it took a full cut; the automatic feed was then thrown in and the time observed. Breakdown was sharp in all cases and left no doubt as to the time of any run. The tools of the first set were tested on logs I and II, those of the second on log III and those of the third on log II.

Table XI

Compositions, Heat Treatments and Lathe Tool Performance of Modern High Speed Tool Steels—(1st and 2nd Series of Tests)

Type of Steel	Brand	Chemical Composition, per cent: C	Mn	P	S	Si	Cr	W	V	Co	Mo	U	Manufacturer's recommended heat treatment: Pre-heat temp., deg. F.	High heat temp., deg. F.	High heat time min.	Tempering medium	Tempering temp., deg. F.
Low tungsten-high vanadium	A	.64	.43	.019	.025	.15	3.43	12.72	1.85	...	...	..	1500	2300	1-1-½	Salt	1000
	B	.60	.31	.023	.026	.35	4.29	13.32	2.15	...	...	..	1500	2400	1-1-½	Oil	500
	C	.64	.26	.026	.016	.37	3.38	13.07	1.98	...	...	..	1500	2350	1-1-½	Salt	1050
Medium tungsten....	D	.66	.23	.035	.018	.43	4.54	14.08	2.07	...	...	..	1500	2300	1-1-½	Salt	1050
	E	.71	.23	.032	.027	.24	4.67	14.31	1.75	...	...	..	1500	2350	1-1-½	Salt	900
High tungsten-low vanadium	F	.65	.29	.031	.021	.17	3.77	17.73	.98	...	...	..	1500	2300	1-1-½	Muffle furnace	1050
	G	.84	.32	.018	.024	.42	3.83	16.13	1.24	...	...	..	1500	2300	1-1-½	Salt	1050
	H	.68	.10	.018	.025	.20	2.95	19.64	.93	...	...	..	1500	2500	1-1-½	Salt	1100
	I	.75	.29	.018	.022	.28	3.69	18.27	.98	...	...	..	1500	2300	1-1-½	Oil	700
	J	.64	.24	.015	.016	.43	3.00	16.98	.87	...	...	..	1500	2350	1-1-½	Salt	1050
	K	.57	.17	.022	.020	.35	4.37	17.58	.79	...	...	..	1500	2300	1-1-½	Salt	1100
	L	.85	.26	.016	.024	.20	2.26	17.05	.96	...	...	..	1500	2300	1-1-½	Muffle furnace	825
	M	.80	.20	.024	.029	.34	2.84	17.86	.73	...	...	..	1500	2300	1-1-½	Oil	450
	N	.66	.22	.024	.025	.25	3.24	17.03	.87	...	...	..	....	....	.....	....	....
	O	.65	.12	.021	.029	.23	3.43	17.31	1.17	...	...	..	1500	2350	1	Salt	1100
Cobalt steels........	P	.68	.19	.018	.021	.37	3.96	13.07	1.63	1.86	...	..	1500	2350	1-1-½	Salt	1050
	Q	.67	.42	.023	.023	.39	3.72	13.50	1.28	4.23	...	..	1500	2300	1-1-½	Salt	1000
	R	.66	.20	.022	.019	.45	3.45	17.80	1.06	2.54	...	..	1500	2300	1-1-½	Salt	1050
	S	.58	.09	.016	.026	.18	2.78	17.56	.93	3.35	...	..	1500	2500	1	Salt	1100
Special steels— (Molybde'm added)	T	.69	.23	.027	.017	.42	3.52	12.88	1.97	...	.71	..	1500	2350	1-1-½	Salt	1050
	U	.64	.23	.014	.020	.42	3.58	16.65	1.10	...	.71	..	1500	2350	1-1-½	Salt	1050
(Uranium added)..	V	.66	.18	.035	.027	.39	3.94	13.80	1.45	...	...	.23	1500	2350	1-1-½	Salt	1100
	W	.64	.26	.027	.027	.17	3.21	17 [illegible]3	.86	...	...	.26	1500	2350	1-1-½	Salt	1100
(Tungsten-less) ..	CC	.65	.55	.027	.044	.48	4.62	....	.68	4.73	4.72	..	1500	2010	15	Salt	900

Table XI (Continued)

Type of Steel	Brand	Endurance in minutes — First set of tests — First grind: B1	B2	B3	B4	B5	Av.	Re-grind: B1	B2	B3	B4	B5	Av.	Av. both grinds	Av. all tests by gr'ps
Low tungsten—high vanadium	A	....	13.75	6.62	14.98	7.65	10.75	10.83	5.45	5.10	9.65	6.23	7.45	8.92	...
	B	12.53	11.47	8.70	10.75	9.63	10.62	7.93	13.27	8.58	9.48	8.23	9.50	10.06	...
	C	10.05	9.45	9.90	10.13	11.77	10.26	7.18	7.03	9.00	8.48	5.00	7.34	8.80	9.27
Medium tungsten..	D	9.52	6.13	4.58	6.12	4.20	6.11	3.38	4.80	5.37	3.27	3.10	3.98	5.05	...
	E	5.45	4.32	4.25	5.35	5.20	4.91	5.37	4.10	6.45	5.45	4.10	5.09	5.00	5.02
High tungsten–low		...	...	...	...	...	...	...	...	...	...	...	...	...	...
vanadium	F	....	5.15	3.33	5.93	4.40	4.70	3.10	3.50	4.43	3.22	3.03	3.46	4.01	...
	G	....	6.93	9.78	9.85	10.27	9.21	10.27	10.02	9.78	8.70	8.55	9.46	9.35	...
	H	3.00	6.08	5.55	5.73	4.52	4.98	5.97	4.87	5.28	4.85	3.17	4.83	4.90	...
	I	5.80	5.82	4.83	6.45	6.08	5.80	4.43	4.37	6.10	4.58	3.68	4.63	5.21	...
	J	3.00	3.13	2.95	3.70	2.80	3.12	2.70	2.22	2.95	2.40	2.97	2.65	2.88	...
	K	3.80	2.00	3.02	3.20	5.60	3.52	2.07	1.70	3.18	2.17	3.17	2.46	2.99	...
	L	4.92	5.55	4.40	7.53	8.80	6.24	2.87	6.67	4.53	5.08	5.30	4.89	5.56	...
	M	4.40	4.73	3.87	4.90	3.65	4.31	5.95	3.62	5.33	3.70	4.70	4.66	4.48	...
	N	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	O	6.62	7.03	6.82	6.80	6.27	6.71	6.67	10.33	11.28	9.57	7.35	9.04	7.87	5.22
Cobalt steels	P	5.43	9.73	7.88	8.92	7.77	7.95	4.82	6.13	8.00	5.97	7.22	6.43	7.19	...
	Q	6.38	5.95	5.63	4.92	6.88	5.95	3.73	4.48	6.53	4.82	5.83	5.08	5.52	...
	R	....	9.12	3.88	7.77	3.95	6.18	4.17	4.83	3.42	4.07	2.47	3.79	4.85	...
	S	10.10	9.13	9.95	8.03	8.33	9.11	6.17	5.60	8.28	5.83	4.58	6.09	7.60	6.29
Special Steels— (Molyb'm added)	T	5.08	5.00	6.53	7.57	8.10	6.46	7.02	5.05	5.18	7.28	5.00	5.91	6.18	...
	U	2.73	3.93	5.12	4.35	5.60	4.35	2.22	2.52	4.35	2.67	3.18	2.99	3.67	4.92
(Uranium added)	V	6.60	8.78	7.32	5.57	7.25	7.10	5.45	5.58	6.05	5.72	4.52	5.48	6.28	...
	W	4.00	4.68	3.18	4.60	4.75	4.24	4.65	3.60	4.27	4.90	2.82	4.05	4.14	5.21
(Tungsten-less).	CC	4.51	4.52	....	....	....	....	4.15	3.27	....	....	....	....	4.11	...

Table XI (Continued)

Type of Steel	Brand	Second set of tests — First grind 1	2	3	4	5	Av.	Endurance in minutes — Re-grind 1	2	3	4	5	Av.	Av. both gr'ds	Av. all tests by gr'ps
Low tungsten–high vanadium	A	....	8.50	7.14	5.30	7.43	7.09	9.48	9.29	5.64	9.04	8.53	8.40	7.82	....
	B	....	9.31	9.12	Tool broke	10.70	9.71	10.06	10.20	9.43	Tool broke	11.58	10.32	10.06	....
	C	....	7.23	9.70	8.50	20.76	11.78	9.01	9.75	9.97	8.21	21.95	11.55	11.68	9.85
Medium tungsten..	D	....	5.07	6.34	5.06	7.76	6.06	3.34	5.34	5.92	5.02	5.97	5.12	5.54	....
	E	....	4.70	9.02	4.59	5.70	6.00	6.74	4.55	7.18	4.97	7.92	6.27	6.15	5.84
High tungsten–low vanadium	F	....	5.39	3.70	5.63	5.04	4.94	4.12	5.93	4.29	5.67	4.07	4.82	4.87	....
	G	....	5.90	5.80	4.53	7.39	5.90	6.55	6.52	6.95	6.31	6.87	6.64	6.31	....
	H	....	4.10	8.36	3.97	9.85	6.57	4.82	6.33	3.93	7.68	6.34	5.82	6.15	....
	I	....	5.46	8.53	5.30	7.97	6.82	5.60	8.54	6.71	7.00	14.70	8.51	7.76	....
	J	....	2.63	4.57	3.73	4.13	3.76	4.31	2.91	5.56	2.77	5.44	4.20	4.01	....
	K	....	2.84	7.80	3.84	3.34	4.46	4.48	2.88	5.01	3.27	4.46	4.02	4.22	....
	L	....	6.68	7.74	5.82	4.95	6.30	7.80	5.90	5.10	6.62	6.43	6.37	6.34	....
	M	....	3.97	5.82	4.41	5.15	4.84	6.07	4.29	5.87	4.05	5.75	5.21	5.04	....
	N	....	3.95	8.61	4.07	5.52	5.54	5.72	3.85	7.97	4.21	8.10	5.97	5.78	....
	O	....	5.43	7.91	4.95	7.65	6.48	9.34	6.63	10.10	5.29	8.96	8.06	7.36	5.78
Cobalt steels	P	....	7.76	12.39	9.60	8.58	9.58	11.35	6.19	14.03	11.23	14.20	11.40	10.60	....
	Q	....	7.27	9.30	6.78	11.93	8.82	7.99	9.87	7.45	9.21	14.87	9.88	9.41	....
	R	....	6.53	6.37	6.97	9.59	7.36	5.95	8.17	6.17	7.27	8.25	7.16	7.25	....
	S	....	11.83	15.21	8.88	22.02	14.48	15.16	12.81	12.57	8.56	24.18	14.66	14.56	10.46
Special steels— (Molyb'm added)	T	....	5.48	8.98	7.33	9.62	7.85	10.23	6.67	13.37	6.84	11.75	9.77	8.92	....
	U	....	4.81	7.89	5.84	7.55	6.52	6.59	3.19	6.93	5.75	8.24	6.14	6.31	7.62
(Uranium added)	V	....	5.87	6.96	6.09	7.34	6.56	6.96	7.82	6.60	9.30	8.17	7.77	7.23	....
	W	....	4.59	6.77	4.96	6.84	5.79	5.25	4.26	9.67	5.03	10.15	6.87	6.39	6.81
(Tungsten-less).	CC	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Discussion of Results

Brand Comparisons

A number of interesting and instructive features are revealed in the results of these tests. The average time that tools of any one brand will cut is greater in some instances after the first grind than after the re-grind. For certain brands the reverse is found to be true while the two averages obtained are often practically the same but none of these three conditions can be considered characteristic of any one type of steel. Large differences in performance of individual tools are observed when made from one bar of steel or when testing both ends of a short tool which has been hardened over its entire length (Table XII).

It is therefore necessary to test a relatively large number of tools and also to repeat the test after they have been re-ground at least once, if results or comparisons of value are to be obtained.

Various brands in the same group show differences in performance which cannot be ascribed solely to variations in chemical composition or heat treatment (for example, steels J and O) but in most cases comparable results were obtained. However, the order of value of different brands of nearly similar performance may be entirely changed by a modification in test, as shown in Table IX, or by substitution of tools from several lots of the same steels for those originally tested. It is therefore necessary to use care in making comparisons. Severe breakdown tests, such as those described will show markedly inferior tools, whether this inferiority is due to the quality of the steel, improper heat treatment, a combination of these or other causes, but the grading of brands of nearly similar performance, often made use of in the purchase of high speed tool steels, is not justified and if made is of no value. This distinction in interpretation of results has usually been overlooked, or at least not sufficiently emphasized by those who have carried out and made use of comparative tests of a similar nature.

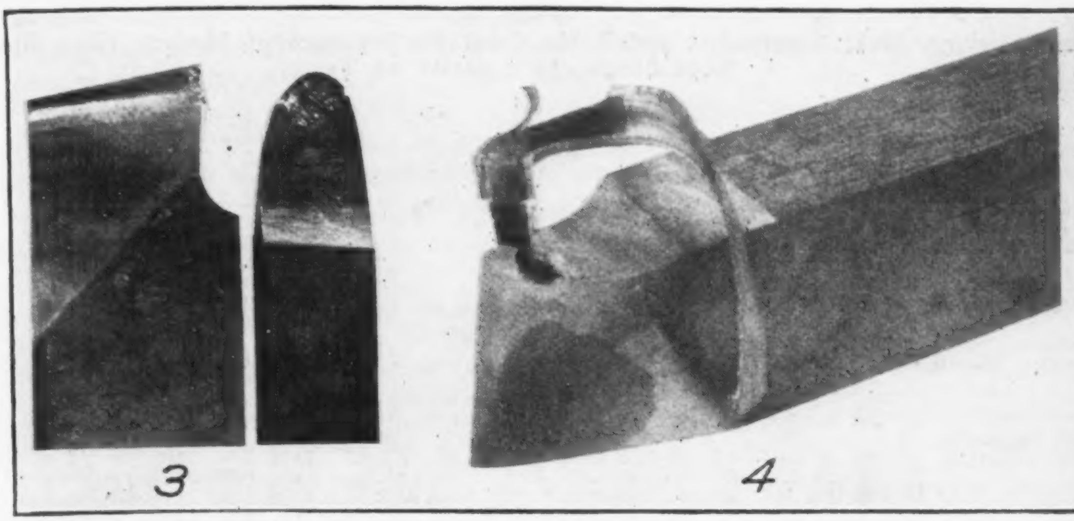


Fig. 3—Typical failures of roughing lathe tools in severe breakdown tests, about ½ size. Note the rubbing off of the nose and "gutter" or groove worn on the top surface of the tools. Fig. 4—"Freezing" of the last thin chip to the nose of tool.

Group Comparisons

In group comparisons, similar precautions are to be observed but some significant variations in the performance of different types are evident as shown in Table X, in which the highest average endurance in each of the 3 series of lathe tests is rated as 100 per cent and the remaining groups given their respective valuations. There is no doubt that the low tungsten-high vanadium and cobalt steels, as groups, are the best. An attempt to differentiate between these, based on the results obtained, would be of little value as their relative positions vary in the several tests without very marked differences in performance. Medium and high tungsten steels and those containing molybdenum or uranium show comparable endurance which may be

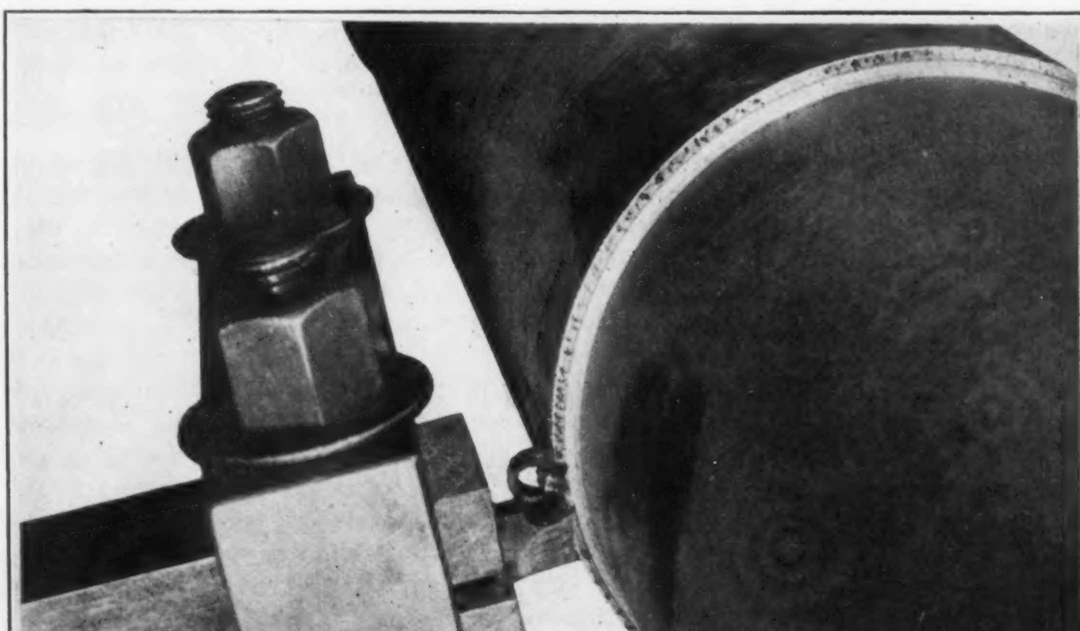


Fig. 5—Failure of a tool under test. Shows "glaze" produced on the test log.

Table XII
Compositions, Heat Treatments and Lathe Tool Performance of Modern High Speed Tool Steels—(3rd Series of Tests)

Type of steel	Brand	Chemical Composition, Per Cent C	Mn	P	S	Si	Cr	W	V	Co	Mo	U	Size of original bar, inches	Pre-heat temp., deg. Fahr.	High heat temp., degrees Fahr.	High heat time, min.	Quenching oil	Heated with muffle furnace from room temperature to Tempering temp., deg. F. 1090-1100° F., held 30 minutes and cooled in air.
Low tungsten—high vanad'm	A	.64	.43	.019	.025	.15	3.43	12.72	1.85	...	...	...	1x½	1600	2300	8	No. 2	
		.74	.31	.008	.055	.51	3.56	13.05	1.73	...	...	...	1x⅝	1600	2300	8	No. 2	
	B	.60	.31	.023	.026	.35	4.29	13.32	2.15	...	...	...	1x½	1600	2300	7	No. 2	
		.73	.49	.012	.028	.37	3.30	13.36	1.71	...	...	...	1x⅝	1600	2300	3	Sperm	
		..	..	...	...	..	...	....	...	...	...	...	1x⅝	1600	2365	3	Sperm	
Medium tungsten	E	.71	.23	.032	.027	.24	4.67	14.31	1.75	...	...	...	1x½	1500	2415	3	No. 2	
		.62	.14	.046	.040	.20	3.50	15.50	1.63	...	...	...	1x⅝	1500	2415	3	No. 2	
		..	..	...	...	..	...	....	...	...	...	...	1x⅝	1500	2370	12	No. 2	
	D	.66	.23	.035	.018	.43	4.54	14.08	2.07	...	...	...	1x½	1600	2415	7	No. 2	
High tugsten—low vanadium	F	.69	.32	.001	.033	.18	3.80	18.00	.87	...	...	...	1x⅝	1600	2415	8	No. 2	
	X	.67	.19	.008	.057	.37	3.33	17.72	1.06	...	...	...	1x⅝	1600	2415	2	No. 2	
	Y	.63	.20	.009	.027	.21	3.05	18.71	.87	...	...	...	1x⅝	1600	2415	7	No. 2	
Cobalt steels..	Q	.76	.34	.008	.061	.27	3.41	14.21	1.52	4.73	...	...	1x2	1600	2300	3	Sperm	
	R	.66	.20	.022	.019	.45	3.43	17.80	1.06	2.54	...	...	1x½	1600	2415	6	No. 2	
	S	.58	.09	.016	.026	.18	2.78	17.56	.93	3.35	...	...	1x½	1600	2415	7	No. 2	
		..	..	...	...	..	...	....	...	...	...	...	1¾x½	1600	2415	3	Sperm	
		..	..	...	...	..	...	....	...	...	...	...	......	....	2385	7	No. 2	
		.72	.08	.020	.017	.11	3.26	18.40	.86	3.10	...	...	1x½	1600	2415	3	Sperm	
		.55	.42	.004	.063	.14	3.10	17.48	.75	3.78	...	...	......	1600	2415	3	Sperm	
Special steels—(Uran'm added)	V	.66	.18	.035	.027	.39	3.94	13.80	1.45	...	...	.23	1x½	1600	2300	7	No. 2	
	W	.64	.26	.027	.027	.17	3.21	17.03	.86	...	...	.26	1x½	1600	2415	7	No. 2	
(Cobalt-molyb'm added)	Z	.65	.28	.028	.045	.28	4.25	17.70	1.00	4.88	1.07	...	1x⅝	1600	2415	3–8	No. 2 or Sperm	
(Tungst.-less)	CC	.65	.55	.027	.044	.48	4.62	....	.68	4.73	4.72	Ni 1.03 Cu .12	Forged from 2x3	1500	2010	15	Sperm	900 45 min.

Table XII continued

Type of steel	Brand	First grind, endurance in minutes 1	1A	2	2A	3	3A	Av. per brand	Re-grind, endurance in minutes 1	1A	2	2A	3	3A	Av. per brand	Av. per brand both grinds, min.	Av. all tests by groups, min.
Low tungsten-high vanadium	A	10.42	11.54	....	....	....	....	....	16.58	4.82	....	....	....	....	....	....	....
		16.37	3.52	....	....	....	....	10.46	17.72	5.72	....	....	....	....	11.21	10.84	....
	B	9.70	19.02	....	....	....	....	....	15.19	7.72	....	....	....	....	....	....	....
		11.12	5.42	16.99	32.38	....	....	....	5.13	9.67	12.42	42.13	....	....	....	....	....
Med. tungsten ...		13.13	15.05	....	....	....	....	15.36	5.51	7.17	....	....	....	....	13.12	14.24	13.11
	E	15.48	8.82	....	....	....	....	....	5.51	9.60	....	....	....	....	....	....	....
		6.85	9.65	....	....	....	....	....	8.19	5.95	....	....	....	....	....	....	....
		9.38	18.52	....	....	....	....	9.81	9.85	8.15	....	....	....	....	7.88	8.85	....
	D	8.68	4.23	....	....	....	....	....	10.53	4.92	....	....	....	....	....	7.09	8.41
Hi. tungsten-low vanadium	F	5.53	4.82	5.99	7.27	....	....	....	8.28	7.05	7.68	7.50	....	....	....	6.76	....
	X	11.70	7.98	....	....	....	....	....	9.52	9.64	....	....	....	....	....	9.71	....
	Y	9.92	11.17	8.17	6.03	....	....	....	12.07	10.52	7.33	5.17	....	....	....	8.80	8.17
Cobalt steels ..	Q	10.65	23.58	10.84	22.85	28.08	13.27	....	16.97	broke	9.22	11.53	17.95	10.92	....	....	....
	R	broke	6.52	....	....	....	....	16.54	broke	8.07	....	....	....	....	12.61	14.73	....
	S	13.37	21.47	....	....	....	....	....	6.08	25.05	....	....	....	....	....	16.50	....
		5.80	10.03	....	....	....	....	....	....	....	....	....	....	....	....	....	....
		8.47	26.25	14.27	7.65	....	....	....	5.65	6.57	....	....	....	....	....	....	....
		....	....	....	....	....	....	....	5.42	10.23	10.67	7.25	....	....	....	....	....
		9.57	10.38	....	....	....	....	....	10.80	10.67	....	....	....	....	....	....	....
		11.25	11.15	....	....	....	....	11.48	18.52	12.80	....	....	....	....	9.86	10.67	12.7[illegible]
Sp. steels—(Uran. added) .	V	10.97	5.28	....	....	....	....	....	5.23	4.23	....	....	....	....	....	6.43	....
	W	6.52	6.70	....	....	....	....	....	10.62	4.64	....	....	....	....	....	7.12	6.78
(Cobalt-molyb. added).	Z	12.58	7.72	1.35	13.75	13.60	6.77	....	13.92	18.40	7.67	22.00	9.07	4.42	....	10.93	10.9[illegible]
(Tungstenless)..	CC	2.94	2.07	....	....	....	....	....	2.04	2.26	....	....	....	....	....	2.32	2.3[illegible]

rated as roughly 60 per cent of that of the low tungsten-high vanadium steels. A tungsten-less high speed tool steel introduced for comparative purposes has a rating of approximately 30 per cent.

The relatively poor showing of the high tungsten steels is significant, especially since they represent the most popular type now manufactured in this country. Many of those tested are well known brands produced by manufacturers who are known to take all reasonable precautions to insure the

Table XIII

Average Energy Consumed by Various Modern High Speed Tool Steels in Severe Lathe Cutting Tests

(Data obtained during 1st set of tests covering tools listed in Table XI)

		Av. Net Watts Consumed by Tools												Av.	
		First Grind						Second Grind						both	Group
Type of steel	Brand	B1	B2	B3	B4	B5	Av.	B1	B2	B3	B4	B5	Av.	grinds	Av.
Low tungsten-high vanadium steels........	A	....	4130	4760	4321	4582	4453	4086	4172	4872	4391	4557	4416	4432	....
	B	3987	4298	4647	4348	4438	4344	4592	4265	4793	5022	4567	4648	4496	....
	C	4005	3868	4784	4523	4462	4328	4199	4514	4366	3898	4752	4346	4337	4422
Medium tungsten steels	D	3912	4442	4677	4720	4482	4447	4495	4798	4572	4240	4839	4589	4518	....
	E	4266	4434	5059	4722	3997	4496	3885	4810	4726	4715	4309	4489	4492	4505
High tungsten steels..	F	....	4116	4956	4245	4629	4486	4146	4348	5077	4345	4566	4616	4492	....
	G	....	4140	4654	4321	4793	4477	4458	4328	4845	4329	4665	4525	4504	....
	H	3869	3998	4583	4432	4292	4235	4462	4593	4908	4101	4689	4551	4393	....
	I	4220	3936	4618	4350	4625	4350	4483	4982	4569	4081	4728	4569	4459	....
	J	4147	4319	4545	4518	4021	4310	4744	4589	4218	4442	4355	4470	4390	....
	K	4126	4668	4495	4973	4192	4491	4863	4772	4587	4567	4506	4659	4575	....
	L	4189	4480	5251	4813	4410	4429	4187	4660	4618	4659	4322	4489	4459	....
	M	4038	5130	4764	4550	4205	4537	4108	4755	4563	4693	4602	4544	4541	....
	N	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	O	4243	3994	4482	4289	3778	4157	4411	4546	4456	4262	4223	4380	4268	4354
Cobalt steels..........	P	4257	4494	5032	4781	4767	4466	4131	4583	4696	4521	4066	4399	4433	....
	Q	4225	3957	4766	4603	4555	4421	4393	4760	4508	4352	4790	4561	4491	....
	R	....	3932	4556	4373	4549	4352	3828	4037	4710	4345	4592	4302	4325	....
	S	4010	3985	4642	4545	4511	4339	4490	4770	4332	4243	4814	4530	4434	4313
Special steels—															
(Molybdenum added)	T	4000	4296	4440	4575	4041	4270	4459	4650	4705	4234	4003	4412	4340	....
	U	4079	4382	4695	4710	4307	4435	4294	4872	4098	4350	4488	4420	4428	4384
(Uranium added)...	V	4132	3884	4550	4459	4299	4265	4696	4709	4645	4361	4713	4625	4445	....
	W	3966	4036	4617	4830	4320	4354	4663	4476	4368	3890	3964	4272	4313	4379

quality of their product, so that the observed inferiority would not naturally be ascribed to generally poor quality of steel, but rather to the fact that the average endurance of this group is less than that of the low tungsten-high vanadium steels or that the heat treatments employed were not the best that could be used. Probably both are contributary causes. The fact that steels containing 1/4 per cent uranium did not develop exceptional performance is in agreement with results obtained by Langhammer[5] under entirely different and more moderate working conditions and likewise with the opinion held by Mathews[6] who recently stated—"so far as our experience goes we have been unable to see that it (uranium) confers any specific benefit."

An interesting feature developed in the first two sets of tests is that a change in working conditions including small variations in tool angles but mainly a decrease in cutting speed from 67 to 61 feet per minute produced a much larger increase in the average endurance of steels containing cobalt or special elements than in the plain chromium-tungsten-vanadium steels (basic

5. A. J. Langhammer: A Comparative Test Upon High Speed Steels. *Chem. & Met. Eng.* 22, pp. 829, 889, 939, 969.

6. J. A. Mathews: Modern High Speed Steel. *Proc. A. S. T. M.*, 19, pt. 2, p. 141.

types). In this respect the cobalt steels show greater variation than those containing molybdenum or uranium and in one case, that of brand S, as much as about 90 per cent increase.

Character of Chips Produced and Failure of the Tools

Some quite definite and more or less regular variations in the character of chips produced during progress of the lathe tests were observed. Almost without exception a long "ribbon" of steel was obtained at the start. The first break would, of course, be largely dependent upon the character of support accorded the metal in its unguided travel but if held by tongs and pulled away from the test lathe an unbroken metal strip, often several hundred feet long, resulted. Shorter and shorter chips were produced as the tool continued to cut and these varied in length from about half a foot at the beginning of what may be called the second stage to a fraction of an inch just before failure. These characteristics were so generally representative that they became a rough indication of the quality of the tool soon after the beginning of the cut. Progressive decrease in length of chips is undoubtedly, largely caused by a gradual change in the most effective portion of the top surface of the tool resulting from abrasive action of the metal being cut. A groove or "gutter" is worn near the nose and forces the chip to curl more and more sharply as the wear increases and because of the cyclic variation in pressure[7] and the fact that the chip is already highly stressed the ribbon breaks into small sections instead of passing freely over the tool at approximately its original top angles. The wear on the entering side near the nose is also an important contributing factor particularly near the end of the cut and both effects are shown in Figure 3.

Breakdown is concomitant with the production of a "glaze" on the test log (Fig. 4). At the moment of failure which generally occurs suddenly, the dimensions of the chip decrease both in direction of the feed and depth of cut. This is probably caused by "springing" of the tool in the holder and is due to greatly increased pressure in all directions resulting from the "dulling" or rubbing away of the nose. If the tool is withdrawn from the test log at the first signs of failure the last thin chip produced will often "freeze" to the nose, as shown in Fig. 5, thus giving concrete qualitative evidence of the high pressure and temperature existing at the moment.

Power Consumption

Thus far, discussion of test results and comparisons have been on the basis of the time required to produce failure in tools working under definite cutting speeds, feeds, depth of cut, etc. Certain groups were shown to have repeatedly better performance than others despite certain small but definite changes in test conditions but the question which almost immediately arises is whether or not more power is consumed by any one set of steels over others in cutting metal at a given rate for equal times. Electric power is measured in kilowatt-hours and that consumed in equal time intervals is proportional to the average kilowatts (energy) during the interval, which may be obtained by ammeters and voltmeters or wattmeters.

The values given in Table XIII for tools used in test No. 1 show that the power consumed by various brands and groups is practically the same in all cases. Differences observed between individual tools are often greater than variations between different brands but are not large and cannot be considered to have any special significance. Thus, the various types of

7. See note (1) with particular reference to data given in folder 12.

high speed tool steels remove the same amounts of metal at equal rates with practically the same power consumption but some have greater endurance than others.

Moderate Breakdown Tests of 1 x ½-inch Roughing Type of Lathe Tool

It was pointed out at the beginning of this report that high tungsten-low vanadium high speed tool steels are the most popular type produced at the present time and subsequently it was shown that the endurance of this group in certain severe breakdown tests was generally much less than that of the cobalt or low tungsten-high vanadium steels. While the conditions under which

Table XIV

Effect of Variation in Feed on the Performance of Various Groups of High Speed Tool Steels

			Endurance in Minutes*			
Group	Brand	Tool No.	3rd grind (.031 feed)	4th grind (.031 feed)	Av. 3rd and 4th grinds (.031 feed)	Av. 1st and 2nd grinds (.045 feed)
Cobalt steels........	S	x2A	23.60	22.83	....	....
	S	T1A	23.27	25.13	....	....
	Q	A104-14A	39.08	17.30	....	....
	Q	A104-14	25.42	15.42	24.00	14.36
High tungsten — low vanadium steels...	Y	A105-2A	17.27	22.30	....	....
	Y	A105-2	35.97	12.35	....	....
	F	A100-27	16.20	9.57	....	....
	X	A102-1	22.70	25.25	20.20	7.84
Low tungsten — high vanadium steels...	B	A101-26A	11.48	19.03	....	....
	B	A101-27A	13.52	12.82	....	....
	B	A101-26	22.48	10.45	....	....
	A	A103-41A	15.58	17.57	15.37	10.08

*Tools were ground to 6 degrees clearance, 8 degrees back slope and 14 degrees side slope with radius of nose 3/16-inch. Tests were made on log No. 11 at 60 feet per minute cutting speed, 3/16" depth of cut and feeds shown.

these tests were made may represent those obtaining in actual practice it is true that a large part of the work for which high speed tool steels are used in various shops is carried out under more moderate working conditions which do not produce the high frictional temperatures obtained in the authors' tests. It is therefore patent to compare the various groups when subjected to more moderate service.

Four tools to represent each of the three most important groups were chosen from the various brands used in test No. 3, as shown in Table XIV. In this selection of tools already tested, an effort was made to obtain groups of 4 or 5 having nearly the same average performances as those obtained in the third set of tests. All tools were ground to form in exactly the same manner as in the previous experiments and the tests carried out represent the third and fourth grinds. They were made with the same test log, tool angles, cutting speed and depth of cut but with approximately three quarters of the feed used in test No. 3.

The relatively poor endurance of the high tungsten-low vanadium steels in the severe tests is not observed under the more moderate conditions of service in test No. 4, a feature which assists in explaining the popularity of the high tugnsten type for general roughing work. However, insufficient

tests have been made to determine whether the performance of the high tungsten steels is equal or better than that of the low tungsten high-vanadium type under the working conditions used.

Lathe Tests of Small Tools

Breakdown tests of large tools, such as have been described in previous sections of this report, are very expensive to make because they require large masses of uniform metal to be cut, heavy equipment and considerable time. The limitations in interpretation of data obtained, as already described, make it questionable whether information derived from repeating this type of test with various steels is commensurate with the cost (except in special instances) especially since comparable performance is observed in the majority of steels in any one group. At least the variation in performance of the various steels (with some exceptions) is not more than would be expected from different lots of the same brand supplied throughout a period of several months. If as much information or satisfactory comparisons could be obtained with smaller tools the cost of tests would be materially reduced.

Accordingly one large tool from each of the low tungsten, high tungsten and cobalt groups was annealed, cut into smaller tools, heat treated, ground and tested in a manner similar to that already described for the large tools. The dimensions of tool chosen were half those used in the first 4 sets of tests namely ½ x 1/4 inch and the radius of the nose was made 3/32 inch instead of 3/16 inch. Tool angles, speed, feed and depth of cut were exactly the same as those used in test No. 4, as was also the test log. On account of the sharper nose required in the small tools and their size, these test conditions, which were considered to be only moderately severe in the case of the large tools, may be considered as somewhat more so for the small tools but probably not equivalent to the severe working conditions obtaining in the first three sets of tests. Results obtained are given in Table XV.

As in the severe tests of large tools the low tungsten-high vanadium steel has better endurance than the high tungsten type but there is not such a large difference as was observed in the large tool tests. The magnitude of the observed effects cannot be compared as the change in size of tools is not the only variable introduced. The important feature is that the small tool tests, carried out under severe working conditions, once more show superiority of the low tungsten-high vanadium steel. The heat treatment of the high tungsten-cobalt steel was inadvertently changed and a low hardening temperature used which without doubt accounts for the relatively poor performance of the steel. It will also be noted that the variations in the performance of individual tools is in general no greater when testing the small tool bits than when using the large tools. However, the same precautions in making tests and in interpretation of results must be observed in both cases. The results obtained, therefore, indicate that when small tool tests are carefully carried out the sensitivity is such as to yield results of some value.

A most interesting feature is revealed in comparison of the performance of ½ x 1/4-inch and 1 x ½-inch tools when removing metal from the same test log under the same cutting speed, feed, depth of cut, etc. With the exception of the ½ x 1/4-inch tools prepared from the cobalt steel, which were hardened at a low temperature, the small tools removed more metal than the large ones before failure. There are a number of variables in the two sets of tests which, as previously mentioned, make inadvisable detailed comparisons of the values reported but it is doubtful whether any of the readily

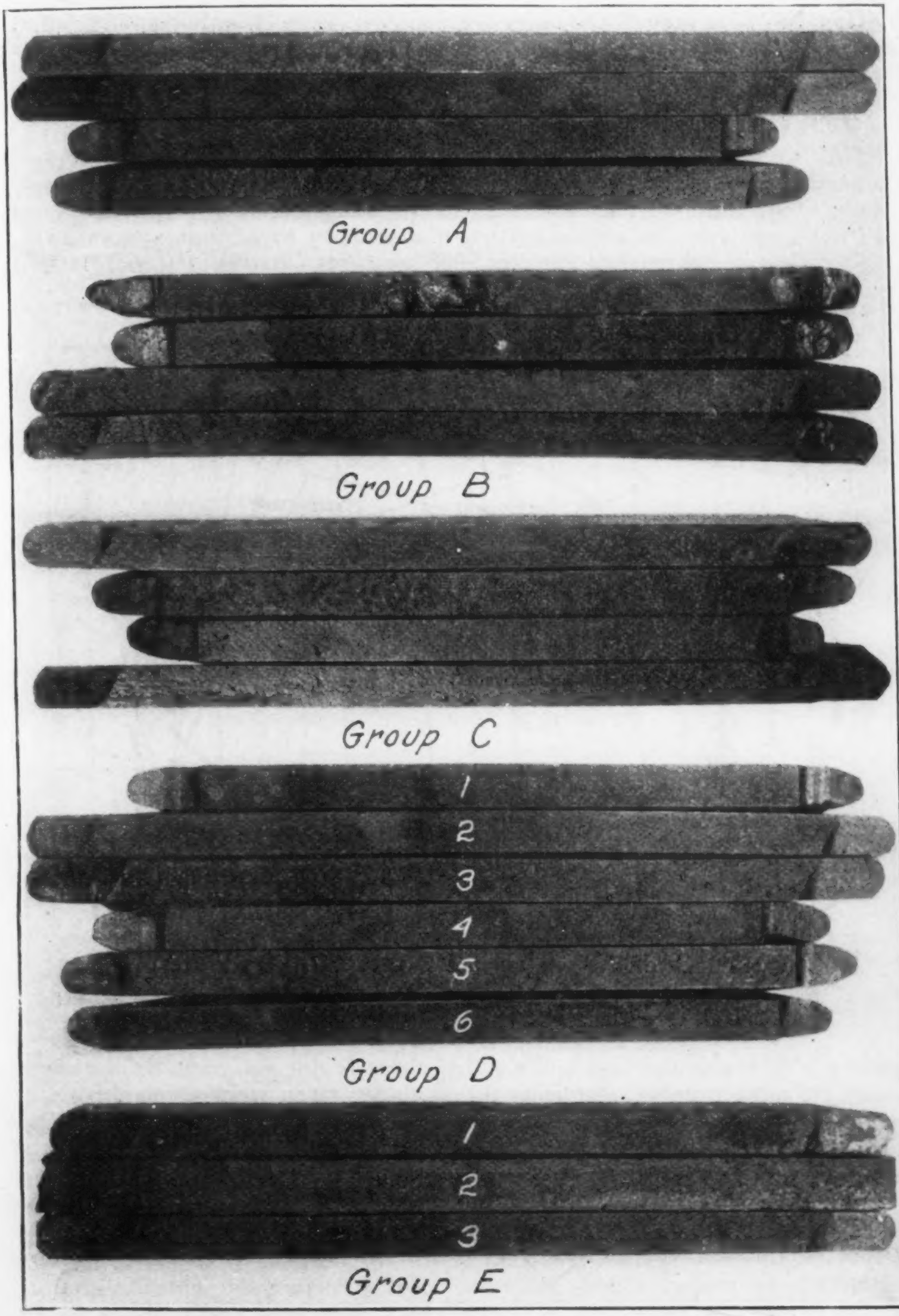


Fig. 6—Surface condition of tools made from various types of high speed tool steels oil quenched from the temperatures indicated: Group A—Low tungsten-high vanadium steels, heated to 2300 degrees Fahr. Group B—Medium tungsten steels, heated to 2370 or 2415 degrees Fahr. Group C—High tungsten-low vanadium steels, heated to 2415 degrees Fahr. D1, 2 and 6—High tungsten steels containing cobalt, heated to 2415 degrees Fahr. D3, 4 and 5—Low tungsten steels containing cobalt, heated to 2300 degrees Fahr. E1 and 4—Special high tungsten steel containing cobalt and molybdenum, heated to 2415 degrees Fahr. E2—High tungsten steel containing uranium, heated to 2415 degrees Fahr. E3—Low tungsten steel containing uranium, heated to 2300 degrees Fahr.

recognizable differences in these two sets of tests adequately account for this result and the authors do not at the present time offer any explanation.

Miscellaneous Tests

Secondary Hardness and Heat Treatment

Examination of Table XI in which are given the heat treatments recommended by different manufacturers shows that these vary widely for brands of the same type composition. High heat furnace temperatures from 2300 to 2500 degrees Fahr., and tempering temperatures between 450 and 1100 de-

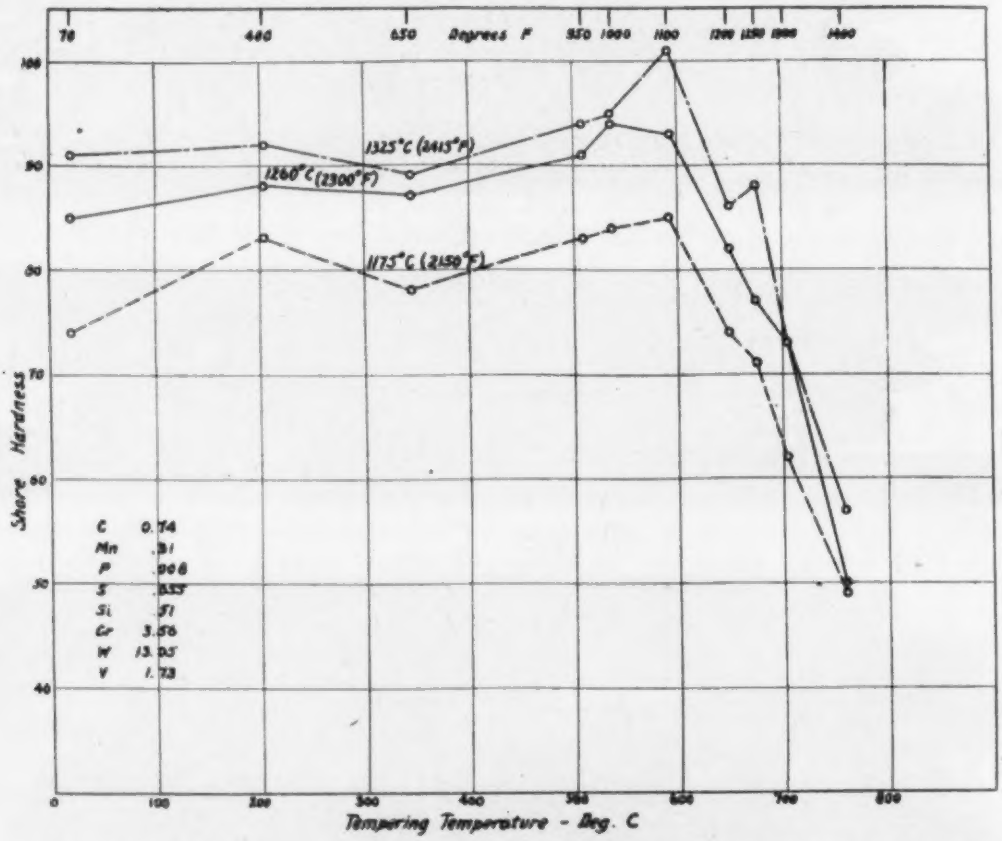


Fig. 7—Re-hardening upon tempering of low tungsten-high vanadium high speed tool steel first oil quenched from various temperatures.

grees Fahr. are found and indicate that there is not yet complete agreement as to the most suitable treatments to use under given working conditions.

The lathe tests made were primarily comparisons of brands or groups of steel and it is therefore not possible to consider in detail the effects of variations in heat treatment upon the performance of different type compositions. However, certain indications were obtained which made it desirable to carry out such special tests as determinations of secondary hardness, character of fracture, etc. and the results are summarized in the following paragraphs.

1. High tungsten steels withstand high hardening temperatures of approximately 2400 degrees Fahr. better than do the medium or low tungsten steels. An indication of this difference is given by groups *B* and *C*, Fig. 6 in which is shown the surface condition of many of the tools used in test No. 3.

2. Low tungsten-high vanadium steels are more sensitive to heat treatment, especially with respect to variations in hardening temperatures between 2150 and 2400 degrees Fahr. than the high tungsten-low vanadium type. This is shown by the more rapid coarsening of structure observed in examination of fractures and by variations in hardness under varying treatments (Figs. 7 to 11 inclusive). Not only are the latter changes smaller in the high tungsten steels for variations in hardening temperatures but they are also less for changes in tempering. However the addition of cobalt to low tungsten steels appears to produce a more stable product.

This does not mean that a given change in high heat temperature,

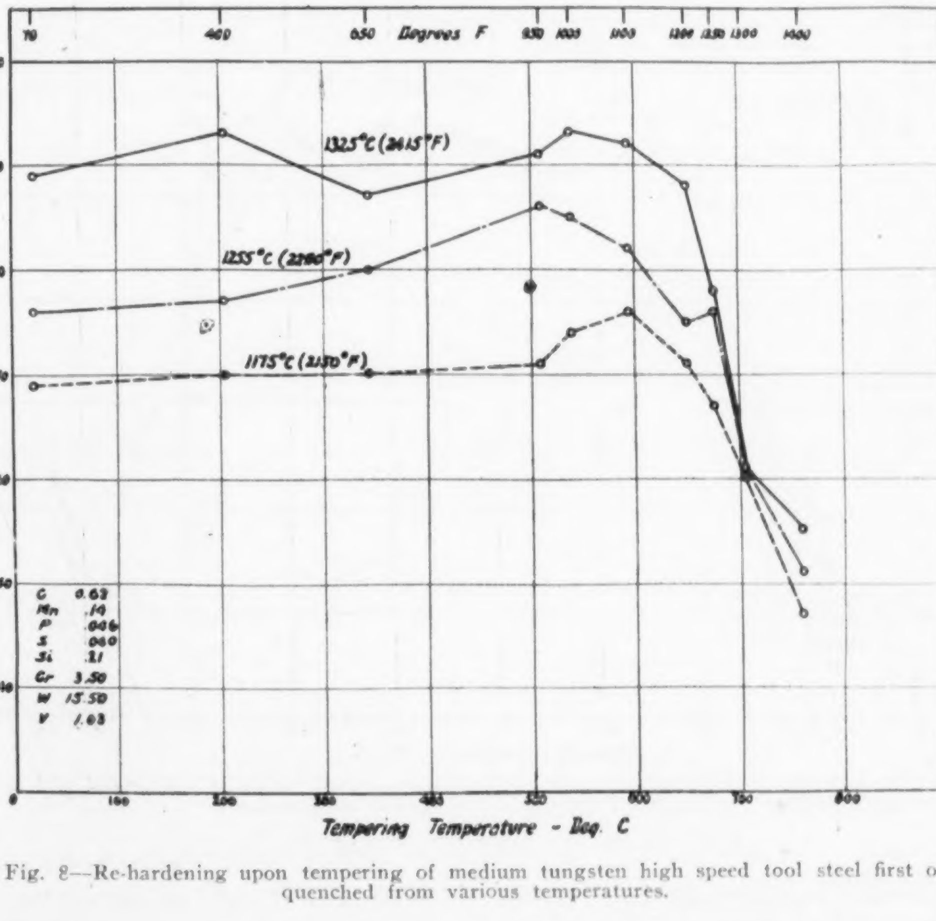


Fig. 8—Re-hardening upon tempering of medium tungsten high speed tool steel first oil quenched from various temperatures.

for example will affect the performance of low tungsten steels to a greater degree than that of the hight tungsten-low vanadium type. This might, however, be true under certain working conditions. The probable relation existing between heat treatment, hardness and cutting qualities of high speed tool steels has recently been summarized in a very clear and concise manner by Mathews[8] as follows:

"The lower the temperature at which the initial hardening is done, the lower will be the temperature at which the rehardening occurs on tempering, and presumably the sooner a tool so treated would fail in severe cutting where the frictional temperature was high. When the temperature in cutting is not extremely high we cannot conclude that the steel would fail sooner than one with a higher re-hardening temperature. In such cases, in my

8. J. A. Mathews: Modern High Speed Steel. *Proc. A. S. T. M.*, 19, pt. 2, p. 141.

opinion, physical or mineralogical hardness plays an important part as distinguished from red hardness, but where the cutting conditions are severe it would appear logical that the higher the temperature of red hardening the longer the endurance of the tools."

Thus the various types of steel which showed marked differences in performance in severe service likewise show differences in their behavior under heat treatment and in physical properties which probably are of importance under more moderate working conditions.

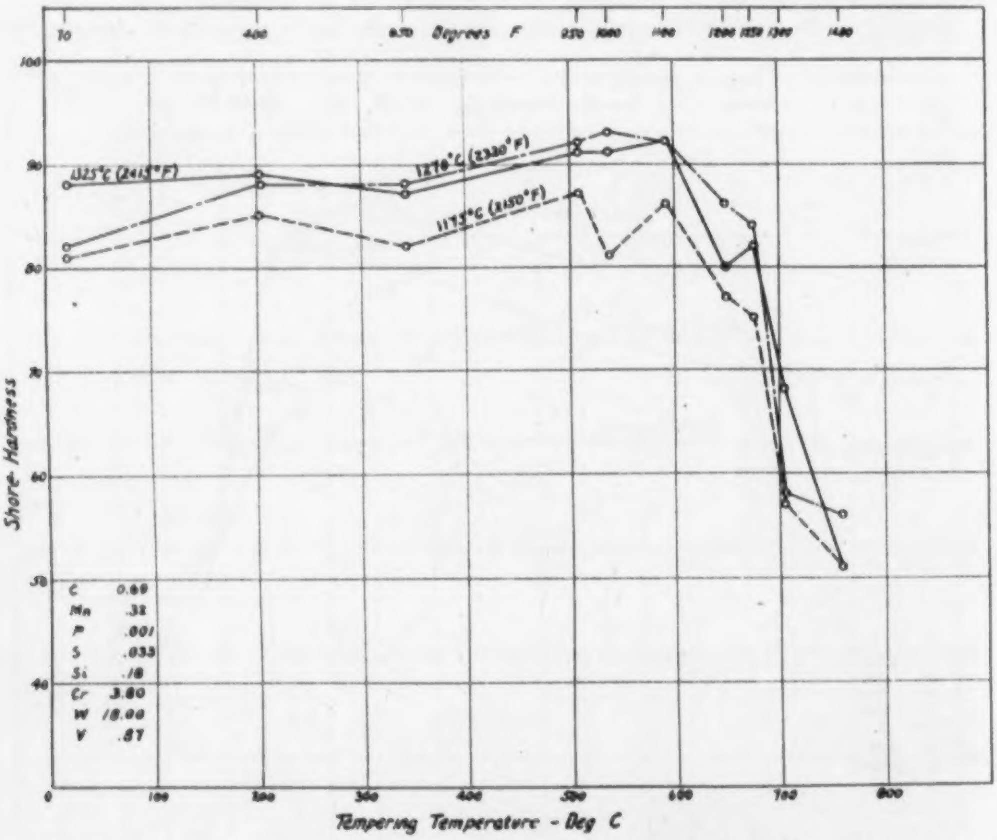


Fig. 9—Re-hardening upon tempering of high tungsten low vanadium high speed tool steel first oil quenched from various temperatures.

Microscopic Examination and Fractures

Mention has already been made of large differences in performance of tools made from the same bar of steel. While the reasons are often obscure on account of the large number of variables readily introduced into breakdown tests it is frequently possible to pick out the principal causes by use of the microscope and examination of fractures. A few illustrations taken from tools used in the cutting tests previously described are contained in Figs. 12 to 16 inclusive.

The appearance of fractures and structure may be very different for steels of similar chemical composition subjected to the same heat treatments whether comparisons are made between tools from the same bar of steel or from different lots or brands. For example, two of the high tungsten-low vanadium steels have moderately coarse fractures while that of steel X, of similar composition, is the finest of all examples contained in Fig. 12. The microstructure of this steel is shown in Fig. 14a and attention is called to the extremely fine grain size and uniformly distributed tungstides, car-

bides, etc. in contrast with the segregation shown in Figs. 14c and 15a. Such differences in structure originated during the progress of manufacture and cannot be eliminated by heat treatment. Steels like those shown in Figs. 14c and 15a often show "fish-scale fractures similar to that reproduced in Fig. 13 and in cutting tests, generally poor and erratic results are obtained.

General Discussion

Composition Versus Quality of Steel and Heat Treatment

Considerable emphasis has been placed on the chemical composition of high speed tool steels though mention has likewise been made of the neces-

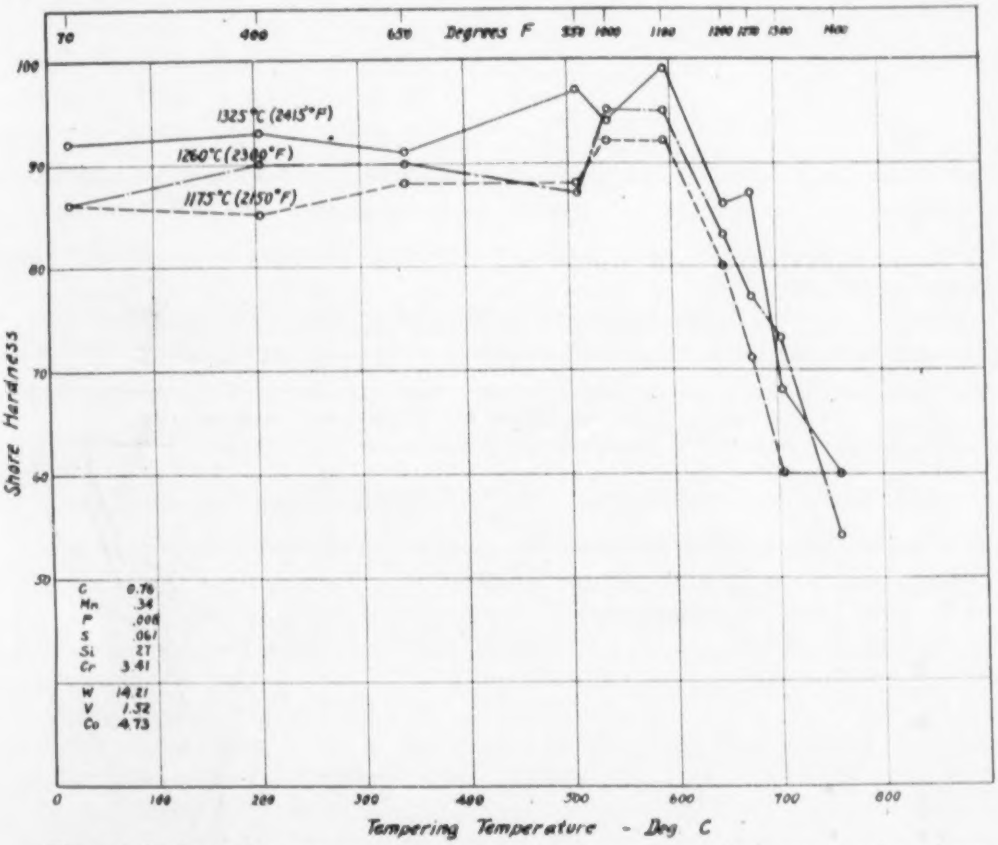


Fig. 10—Re-hardening upon tempering of medium-low tungsten high speed tool steel containing cobalt, first oil quenched from various temperatures.

sity of high grade raw materials, good melting practice and care in fabrication in producing alloys of superior performance. Clean, sound metal, free from impurities and excessive segregation including "stringers" of carbides, tungstides, etc. is essential and it is true that the behavior of 2 lots of practically identical composition and heat treatment may be quite different in service because of variations in the quality of the steel. However, its composition is likewise of importance and should not be disregarded. If it is not within certain limits the steel cannot have satisfactory performance; on the other hand, the mere fact that the metal comes within the ordinary limits of chemical composition does not insure its behavior in service.

The practice of purchasing and using high speed tool steels solely by name is not the ideal method for there is always the possibility of change of type resulting from a variety of causes. This may result in decreased performance with rise in tool costs or require a modification in treatment for

maintaining comparable service. While such conditions may not often be encountered they are nevertheless observed and therefore are of importance. In an instance recently brought to the attention of one of the author's two organizations were using the same brand of steel. In the first case low tungsten-high vanadium steel was regularly supplied while the second plant reported this brand to be the high tungsten-low vanadium type. In view of

Table

Heat Treatment and Performance of Small Lathe Tools

Brand	Pre-heat temperature, degrees Fahr.	High heat temperature, degrees Fahr.	High heat Time, Minutes	Tempering temperature, degrees Fahr.	First grind 1	2	3	4	5
B	Low tungsten—high vanadium steel								
	1600	2300	2	1090	26.90	31.75	25.95	24.28	28.78
F	High tungsten—low vanadium steel								
	1600	2415	2	1090	24.38	36.10	20.83	26.85	16.33
R	Cobalt steel (high tungsten type)								
	1600	2300	2	1090	25.73	23.93	30.37	15.83	14.47

*Tools broke in test.

Size of tools: ¼" x ½" with radius of nose $\frac{3}{32}$". Tool angles and properties of test log same as those

the test data previously described no further comments regarding such a condition need be made.

A lot of a well known brand, normally of the high tungsten type containing about 1 per cent vanadium recently gave one organization considerable

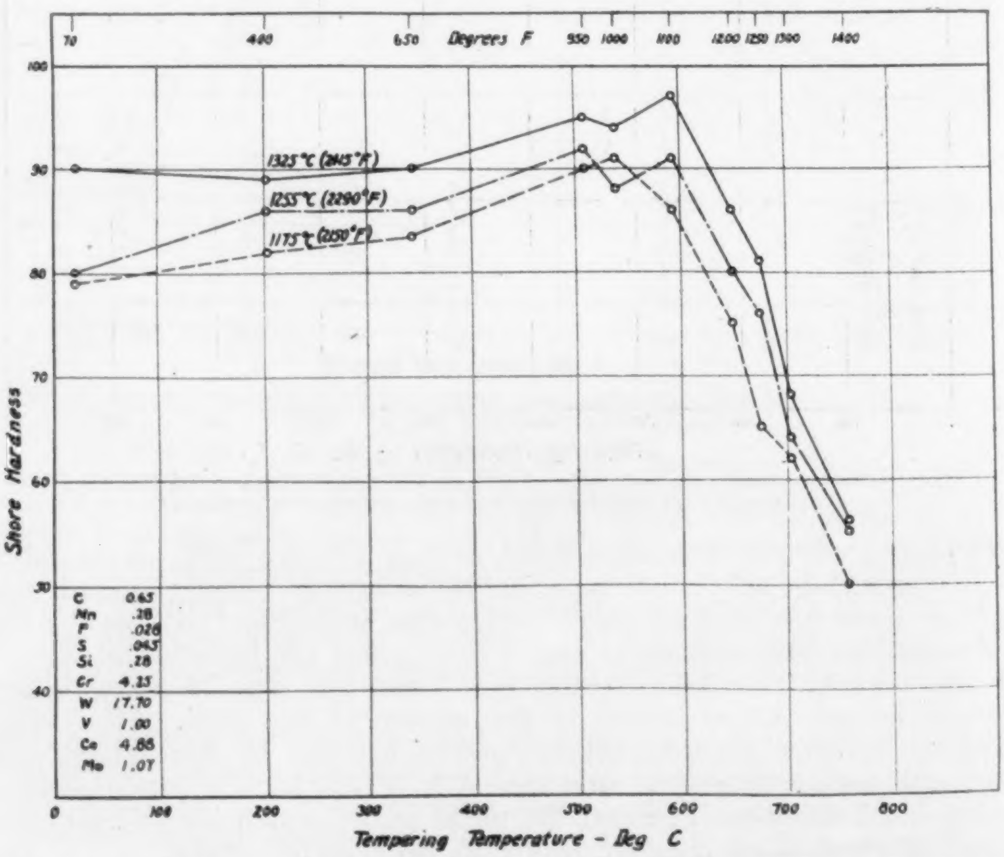


Fig. 11—Re-hardening upon tempering of high tungsten high speed tool steel containing cobalt and molybdenum, first oil quenched from various temperatures.

trouble and had only about 1/5 its ordinary endurance. Examination developed the fact that less than 0.2 per cent vanadium was present. This material was

undoubtedly shipped in error and no difficulty would be encountered in obtaining replacement but the cost in time and labor of such errors, to the many shops not ordinarily checking the composition of high speed tool steels but buying and using them solely by name, is of considerable magnitude.

Having secured steel of satisfactory quality and of suitable composition great care is required in heat treatment. Methods including accurate temper-

XV

Prepared from Three Types of High Speed Tool Steels

Endurance in Minutes	Re-grind						Average both grinds	Performance, per cent of best type
6	1	2	3	4	5	6		
22.15	32.40	29.97	17.40	.....	.....	.....	26.62	100
17.43	30.22	26.03	27.65	.....	.....	19.87	24.57	92
21.63	*	*	*	*	20.38	20.38	21.99	81

used in Test Series No. 3, Tables VII and VIII.

ature control but disregard of the time factor are not satisfactory. When it is considered that in many cases lathe tools are placed in heat treatment furnaces which are maintained at temperatures sufficient to melt the steel (See Figs. 14b, 15a, 15b and 16) and that therefore the time element, is largely depended upon in correctly carrying out the hardening operation it is not difficult to understand why erratic and unsatisfactory results are so often produced.

Breakdown Tests for the Purchase of High Speed Tool Steels

The chemical composition, quality of metal and heat treatment are three most important factors to be considered in the purchase of high speed tool steels. The advice of manufacturers can readily be obtained regarding available types best suited for definite service or if desired comparative cutting tests can be made. No difficulties should then be encountered in securing steel within satisfactory limits of composition.

While heat treatment is normally under complete control of the consumer it becomes of importance in selecting the type of steel. For example, slight superiority in performance of one composition might be counterbalanced by greater sensitivity to heat treatment or the necessity of using very high hardening heats for development of maximum endurance resulting in excessive scaling of tools, shorter furnace life and generally higher production costs. Assuming correctly balanced composition and heat treatment, the quality of metal may be considered as the summation of all other factors influencing the true performance of the steel. It is largely because of variations in this respect, that competitive breakdown tests have come into use though their purpose is comparison of finished products, the performance of which is influenced by all factors mentioned. It is questionable, however, whether such tests have really answered the purpose.

As already indicated the grading of brands or steels of nearly similar performance is not justified because the order of value may be entirely changed by minor variations in test conditions or by introduction of tools made from different lots of the same brand. Likewise there is no assurance that test bars supplied prospective purchasers for a purely competitive test really represent the average product of various manufacturers. In many cases they do but in others a portion of the steel later supplied has been

below the standard. Unless suitable methods are employed to check subsequent shipments against performance in the competitive test the variations encountered may be much greater than the differences originally found between various steels.

Unless breakdown tests are made under conditions very closely approximating those of actual service the results obtained will mean little or nothing

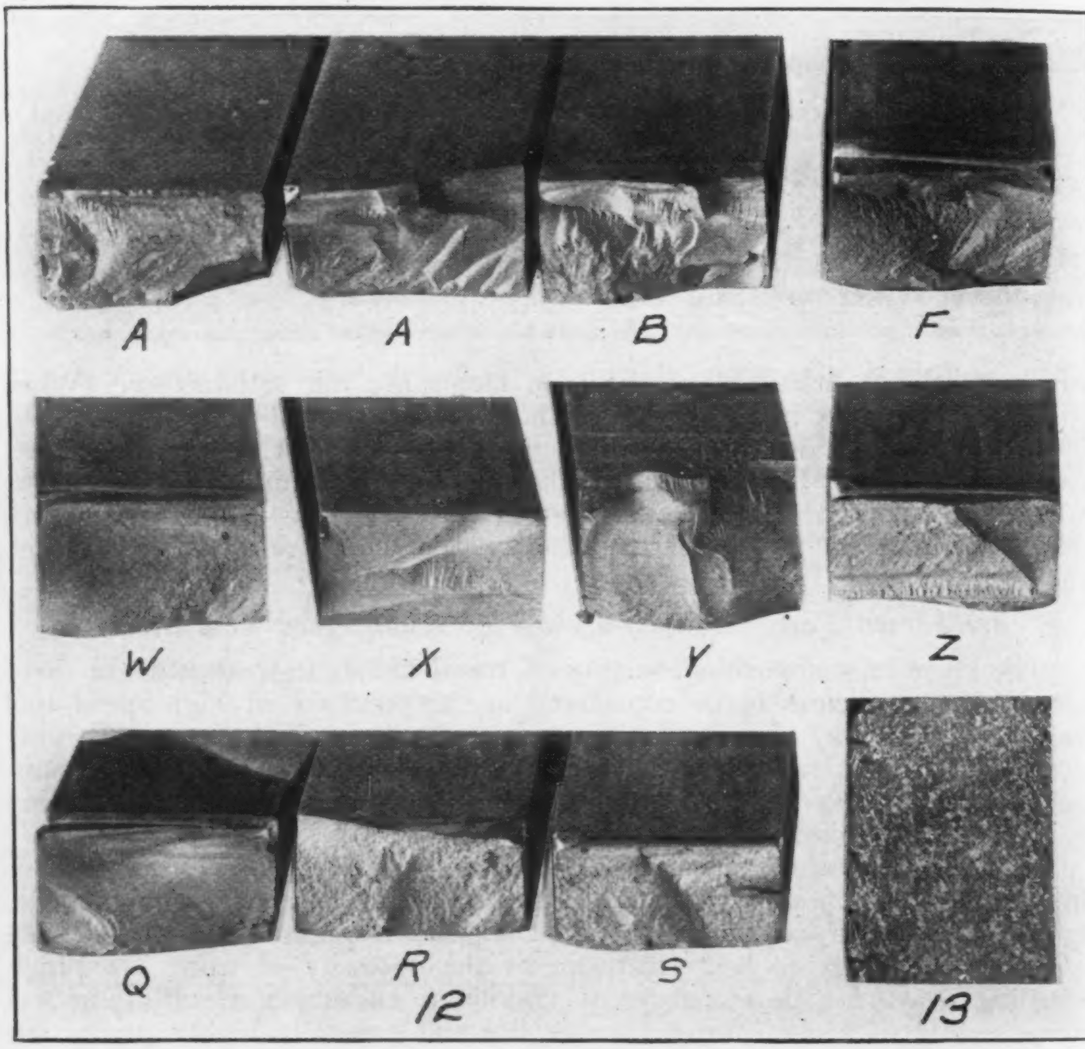


Fig. 12—Fractures of some of the lathe tools subjected to breakdown tests, about one-half size. Tools shown are those hardened over their entire length and used in test No. 3. Letters shown represent the various brands.

Fig. 13—"Fish scale" fracture in high speed tool steel. Note quenching and grinding cracks.

and may actually be misleading for, as previously shown, two types of steel may have comparable endurance under certain test conditions but if these are materially changed the endurance of one may become much greater than that of the other. Results of breakdown tests can only be accepted if a large number of tools are tested and the averages of at least two grinds are used in interpretation of results. They may therefore be employed to detect steel of highly qustionable quality or to differentiate between steels or groups of widely different performance, but are not satisfactory for competitive comparisons used as the basis of purchase. Rather would the authors recommend the purchase of definite types of high speed tool steel on the basis of price from

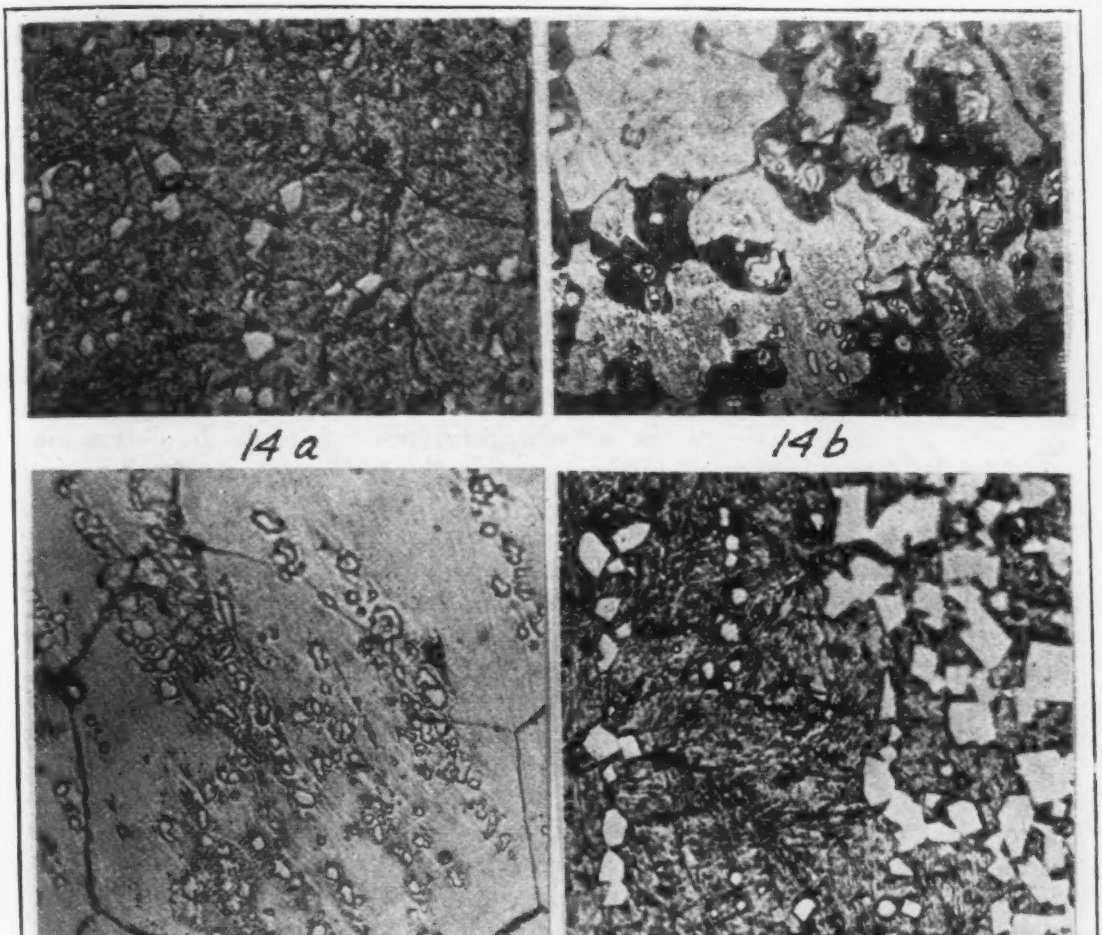


Fig. 14a—Characteristic structure of steel X. X 1000. Fig. 14b—Zone of partial melting observed in tool of steel S. X 500. Fig. 14c—Section near top surface of tool shown in 14b. X 500. Fig. 15a—Section of tool of steel S shown in Figs. 16b and 16c X 750. Fig. 15b—Surface of heat treated tool S showing effects of sweating. X 750. Fig. 16—Cast high tungsten-low vanadium high-speed steel for comparison with Fg. 16b. X 750.

manufacturers known to produce a uniformly high grade product and the use of suitable inspection tests to insure the quality of various shipments made. The establishment of a selected list of producers should not be objectionable for it would be open to all organizations able and willing to demonstrate high quality of product. Inspection tests might include macroscopic etching, fracture, chemical analysis and even microscopic examination and breakdown tests, the last mentioned to insure the performance of steel being equal or better than a carefully prescribed minimum which could first be established.

Summary and Conclusions

Important features developed or conclusions drawn from the described tests may be summarized as follows:

1. Breakdown tests, in which endurance of tools is determined under definite working conditions, are not satisfactory as the basis of purchase for high speed tool steels.

2. While competitive comparisons of brands of nearly similar performance are not justified, owing to the qualitative nature of this type of test, relatively large differences may be ascertained with certainty providing sufficient tools are tested and averages of at least 2 grinds are used in interpretation of results.

3. In certain severe breakdown tests with roughing tools on 3 per cent nickel steel forgings, in which high frictional temperatures were produced, it was found that the performance of commercial low tungsten-high vanadium and cobalt steels was superior to that of the high tungsten-low vanadium type and special steels containing about 1/4 per cent uranium or 3/4 per cent molybdenum. The average power consumption in all cases was practically the same so that this factor need not be introduced in comparisons which may be made on the basis of endurance of the tools.

4. Modification in test conditions including small changes in tool angles but principally changes in cutting speed more markedly affected the performance of steels containing cobalt or special elements such as uranium or molybdenum than that of the basic types (plain chromium-tungsten-vanadium steels).

5. The relatively poor endurance of the high tungsten steels under severe working conditions was not observed in more moderate tests, made on the same test log with equal cutting speed and depth of cut but with reduced feed, in which the frictional temperatures produced were not so high. Also in these latter tests the performance of the cobalt steels was better than either the low or high tungsten steels.

6. Hardness determinations and examination of fractures indicate that the various types of commercial high speed steel show differences in behavior under heat treatment and in physical properties which probably are of importance under moderate working conditions, and might counterbalance slight advantages in performance.

The authors take pleasure in making acknowledgement to Lt. Commander H. L. Merring, U. S. N. whose generous co-operation made it possible to carry out much of the work and assemble the test data described in this report, and to Mr. T. G. Digges, Asst. Physicist, Bureau of Standards, for valuable aid in carrying out many of the tests. Acknowledgement of assistance is also made to Mr. T. H. Johrden, Machinist Inspector and Mr. J. W. Talley, Asst. Chemist, of the U. S. Naval Gun Factory.

CARBURIZING AND DECARBURIZING IN CASE HARDENING

H. B. Knowlton

Abstract of Paper

This paper discusses the carburizing and decarburizing actions which make for the success or failure of the case hardening method in commercial practice. The following points are brought out. Successful case hardening must produce cases of the proper depth, per cent of carbon, and free from decarburization. The temperature of the lining of the furnace and the ratio of the weight of the charge to the weight of the lining are important factors determining the speed of heating. The use of test pins for determining the depth of case before removing the charge from the furnace, is recommended. The thickness of case on pieces of different sizes and shapes carburized together is shown.

The per cent of carbon in cases of the same depth may vary greatly. The carbon content is best estimated by use of the microscope. The temperature, pressure, method of packing, speed of cooling, and the nature of the carburizing material affect the per cent of carbon and the depth of penetration. Reference is made to Giolitti's experiments and his statement of laws governing carburization. The effect of uniform and nonuniform materials is shown.

Factors which may produce decarburization are discussed. Experiments are described showing the effect of different carburizing materials in poorly sealed pipes. Poor carburization and decarburization of pieces near the top but not uncovered, is shown. Effect of carburizing in well sealed box is shown. The use of strong carburizing materials and well sealed containers is advocated. The paper is illustrated with tables, photographs and photomicrographs.

THERE can be little doubt that the case hardening process, when properly carried out, can produce very desirable results. By this process, articles can be produced, which have the maximum surface hardness combined with the maximum internal toughness. However the process has its opponents, because of the numerous errors which may occur. It is the purpose of this paper to discuss some of the carburizing and decarburizing factors which tend to make for the success or failure of the case hardening process. In order to be successful the methods used must produce articles which have the proper depth of case, the proper per cent of carbon in the case, and which are free from surface decarburization.

Depth of Case

That an accurate control of the depth of case is necessary, needs little

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A paper to be presented before the Detroit Convention October 2-7. The author, H. B. Knowlton, is Instructor in Metallography and Heat Treating, Milwaukee Vocational School.

discussion. If the case is unnecessarily deep, particularly in pieces having thin sections, there is a sacrifice of toughness. On the other hand, if the case is too thin, it will not stand up in service. Yet in spite of the fact that the importance of the depth of case is universally recognized, one of the most common errors is inaccurate control of the depth of carburization.

In many places it is the practice to run the carburizing heat for a certain number of hours at a given temperature, and then remove the pots assuming that the proper depth of case has been produced. The temperature is usually judged by one or more thermocouples placed somewhere in the muffle of the furnace. These couples measure the temperature of the furnace gases and not the temperature of the inside of the carburizing pots or boxes. Providing the temperature of the inside of the boxes was actually maintained at a given degree for a certain number of hours, and the same kind of steel and the same carburizing material were used, the same depth of case should be produced on each run. But when the heat is run for a certain number of hours after loading or after the thermocouple in the muffle, records the desired temperature, constant results are not always obtained. This is due to the fact that the length of time consumed in heating the boxes entirely through is a variable depending upon a number of factors. The temperature indicated by the thermocouple does not tell the whole story.

For example, consider a furnace fired by gas or oil. The furnace gets its heat directly and indirectly from the burning of the gas or oil. Some of the combustion usually takes place in a combustion chamber outside of the muffle proper. The muffle of the furnace is filled with burning gases and hot waste gases. The major part of the heating is done by these gases. When the lining of the furnace is cold, the heat of these gases is absorbed in heating the lining and taking care of heat losses through the walls, doors, and flues. When the lining is thoroughly heated, the hot gases have to take care only of the heat losses. When a cold charge is placed in a hot furnace it absorbs heat from the lining and from the furnace gases. So when a cold charge is placed in a thoroughly heated furnace, the heat of the furnace gases is utilized solely in heating the charge and taking care of the heat losses, but when the furnace lining is cold or only partly heated, the heat of the furnace gases is used not only in heating the charge and taking care of losses, but part of it is used in heating the lining of the furnace. It is obvious that in the former case the charge will be heated more rapidly, assuming, of course, that the temperature and quantity of the furnace gases is the same in both cases. The thermocouple in the furnace, indicates only the temperature of the gases. Of course the temperature of these gases is affected by the temperature of the lining and the charge, but the temperature of the gases can not be accepted as a criterion for judging the temperature of either the lining or the charge. Radically different conditions with regard to the latter, may be represented by identical pyrometer readings. Again, even when the lining of the furnace is thoroughly heated through, the ratio of the weight of the charge to the weight of the furnace lining, is an important factor influencing the speed of heating of the charge. If one small pot is placed in a hot furnace, it will be heated through much faster than a number of pots of the same size in a smaller furnace, or even in the same furnace. And yet a comparison of the pyrometer readings might fail to show how great the difference in the speed of heating really is.

In some places it is customary to count the time of the carburizing heat, beginning with the time when the outside of the pots appear the color of the

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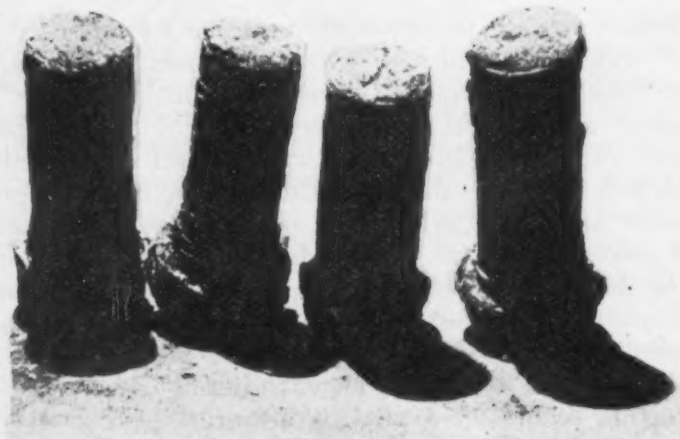

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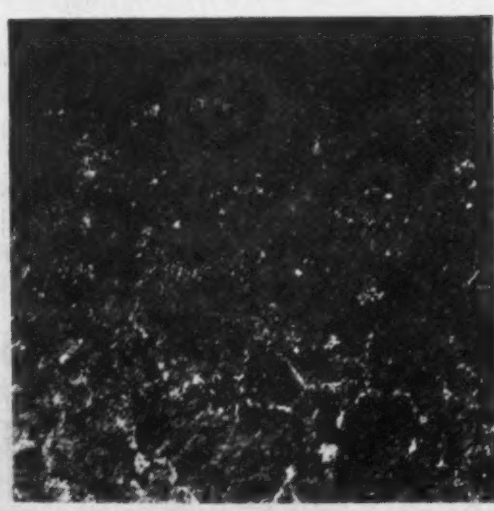

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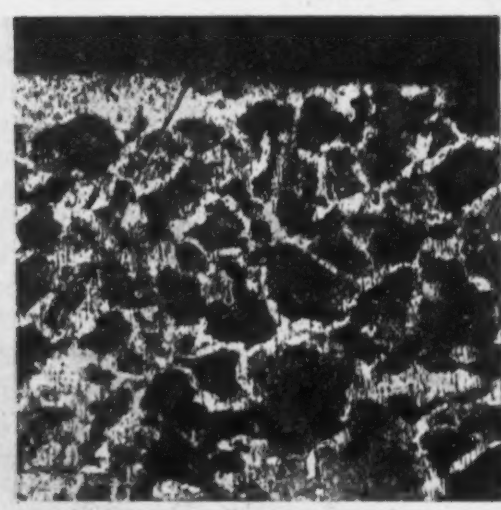

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Fig. 1—Photograph of etched fractures of pieces carburized together. Note that the depth of case is the same on each. Fig. 2—Photograph of pipes at the end of the carburizing heat, showing the condition of the seals. Fig. 3—Photograph of pipes after removing the clay, showing the shrinkage. Fig. 4—Photomicrograph of bar in the center of pipe No. 1 containing mixed compound. X 150. Fig. 5—Photomicrograph of bar in the top of pipe No. 1 containing mixed compound. X 150.

thermocouple, and the latter records the desired temperature. This is better than starting from the time of charging, but it is not a safe way to judge when the center of the pots will reach the temperature. In some other hardening rooms it is the practice to withdraw a test bar from the center of one of the pots and judge by its color whether the inside of the pot has reached the temperature of the furnace. This is still better but is open to personal errors. Besides when the speed of heating is slow there may have been considerable carburizing before the inside of the pot reached the final carburizing temperature, while if the speed of heating was very rapid there would have been very little time for carburizing before the inside of the pot reached the final temperature. So this method may also be far from perfect.

Use of Test Pieces

A still better method is employed in some of the case hardening rooms. Several test pieces are laid up with each heat. When it is considered that the heat should be ready to come out, one of these test pieces is removed, hardened and broken, and the depth of the case is determined by examining the fractures. If the required depth of case has been reached, the heat is pulled. If not, the pot from which the test piece was taken, is sealed up again and returned to the furnace and the heat is run longer, until the test pieces show the proper depth of case. The objection which is often raised to this method, is that a small piece will not indicate the amount of case received by a larger piece in the same pot or box. It seems to be a common belief that thin pieces will acquire case much faster than thicker pieces in the same part of the same carburizing box. It is sometimes even stated that the thin section of a piece will be cased much deeper than the thick section of the same piece. A fracture or an etched cross-section of a carburized piece will show that this is not true. The inside edge of the case follows the profile of the piece, only rounding slightly at the corners. With regard to pieces of different sizes and shapes, which are near each other in the carburizing box, attention is invited to Fig. 1. This shows three pieces quite different in size and shape which were within an inch of each other in the carburizing box. As the box was allowed to cool before breaking the seal, it is obvious that the conditions of carburizing of each piece was the same. After carburizing the pieces were hardened broken and etched in nitric acid. The case shows black. It will be noted that the depth of the case is the same on all three pieces. Within reasonable limits it may be safely said that the depth of case on a small test piece may be taken as a criterion for judging the depth of case on the work in the same pot or box. The analysis of the steel must be the same in both cases, as alloys affect the speed of carburization.

In one large case hardening room this method has been employed for several years. Several test pieces are used in each heat. It has been found that about 95 per cent of the heats come out on scheduled time, but the saving of the other 5 per cent is worth the cost and trouble of using test pieces. Furthermore it has been found that heats are more liable to drag behind on Monday than any other day, due to the cooling of the furnaces over Sunday. It has also been found that the test pieces act as an early indication of trouble with the furnaces. As there are several test pieces in each heat, they show whether the furnaces are heating uniformly. When the baffles start to crack, the flues become plugged up, the pyrometers get out of order, or anything else happens to change the heating conditions, th test pieces indicate

that something is wrong.

Carbon Content of Case

One of the most important factors in case hardening is the per cent of carbon in the case. Unfortunately this can not be readily seen by examination of the fractures. The depth of the case may be the same in two pieces and if the hardening is good, the grain may be refined, and yet there may be considerable difference the per cent of carbon. It could not be expected that a case containing only 0.70 per cent carbon would have the same wearing qualities as one containing 1.00 per cent carbon. The scleroscope and the file test in commercial practice often fail to show the per cent of carbon. The microscope shows this very plainly, but unfortunately it is not used as much as it might be in commercial work. The amount of carbon at the surface will be affected by kind of carburizing material used, the temperature, the pressure, the method of packing, the speed of cooling, and sometimes the shape of the piece carburized. On slow cooling there is a tendency for the excess carbides if present to segregate at the surface. Where two or more surfaces come together to form an edge or a corner this tendency is increased, thus causing the carbon content at that locality to be very high. Quenching from the lowest possible hardening temperature does not change this, consequently pieces slowly cooled and single quenched are liable to be brittle at the edges and corners. A high quench prevents this condition.

Giolitti's book on cementation[1] is probably the most exhaustive and scientific treatise ever written on the subject. He shows that when the ordinary solid carburizing material is used that the carburizing action is due to the action of carbon monoxide or CO. He also shows that carburizing may be done with certain hydrocarbon gases. Other writers[2] have shown that cyanides, while they may add carbon to the steel, also add nitrogen, and that the hardness in the quenched pieces is due in part at least, to the nitrides formed. In this paper only the carburization due to the CO will be discussed, as this is the most common form of carburization, when solid carburizers are used. Based on his numerous determinations, Giolitti stated several laws which govern carburization by CO. He proved that the temperature, the pressure, and the quantity of CO all had an effect on the carburization. In practical work the temperature is governed to some extent by the effect of the temperature upon the steel. When the carburizing is done in pots or boxes, the amount of pressure obtainable is very limited. The amount of the carbon-monoxide gas, however can be controlled by the selection of the carburizing material. Giolitti stated: "All other conditions being equal, the concentration of carbon in the cemented zone increases when the quantity of pure carbon-monoxide which comes in contact with unit surface of the steel during cementation, increases." So anything which would increase the amount of CO should increase the concentration of carbon in the case. Of course the concentration of carbon in the steel can not be increased beyond the limit of solubility of carbon in the steel at the carburizing temperature. This probably explains why coke which may contain 80-90 per cent carbon, but which does not yield much gas on heating, and which burns slowly, is a poor carburizer, while bone and leather, which contain relatively small amounts of carbon, are good carburizers. However, both bone and leather wear out rapidly because the small amount of carbon present is quickly exhausted. Even with other types of carburizers there is a gradual

1. Cementation of Iron and Steel; Giolitti.
2. Brophy and Leiter; Trans. A.S.S.T. March, 1921.
Ruder and Brophy; Chem. & Met. November, 1921.

change on use. The more easily volatile and combustible constituents are given off first. Many of the commercial and home made "compounds" contain certain chemical carbonates which are commonly called energizers. The function of these carbonates is to liberate carbon dioxide, which on coming in contact with excess amounts of hot charcoal, coke or other forms of carbon in the carburizing pot, is converted to carbon monoxide, thus increasing the quantity of carbon monoxide in the pot. The result is an increase of concentration of carbon in the case. That this is so, can be readily seen by compar-

TABLE I

Sixteen Specimens of S. A. E. 1020 Steel 1½ Inches Long by ⅜ Inches in Diameter Carburized for 3½ Hours at 1700 Degrees Fahr.

Carburizing Material used	Bar Number	Position in pipe	Depth of case in inches	Maximum carbon content at the surface
Pipe No. 1 Charcoal	1	Bottom	0.047	Less than 0.90 per cent
	2	5 inches from top	0.039	Less than 0.90 per cent
	3	3 inches from top	0.027	Less than 0.90 per cent
	4	1 inch from top	0.024	Very uneven 0.50—0.70 per cent
Pipe No. 2 All new Compound	5	Bottom	0.055	More than 0.90 per cent
	6	5 inches from top	0.055	More than 0.90 per cent
	7	3 inches from top	0.047	Slightly more than 0.90 per cent
	8	1 inch from top	0.051	About 0.90 per cent
Pipe No. 3 Soda ash in the bottom, Charcoal in the top	9	Bottom. In the chemical	0.01—0.039	Less than 0.90 per cent In some places very low
	10	5 inches from top In charcoal	0.043	Considerably Over 0.90 per cent
	11	3 inches from top	0.035	About 0.90 per cent
	12	1 inch from top	0.035	About 0.90 per cent
Pipe No. 4 Barium carbonate in the bottom, charcoal in the top.	13	Bottom. In the chemical	0.027 max.	Less than 0.90 per cent Uneven. In some places about 0.50
	14	5 inches from top in charcoal	0.039	About 0.90 per cent
	15	3 inches from top	0.031	About 0.90 per cent
	16	1 inch from top	0.027	About 0.90 per cent

ing the photomicrographs, Figs. 4 to 13 inclusive, of bars carburized in pure charcoal, with those of bars carburized under the same condition in a compound containing charcoal, coke, and chemical. One reason for the use of carbonates of the alkali and alkali-earth groups, is that these chemicals when exposed to air after use will reabsorb CO_2 from the atmosphere, and consequently they can be used over and over. On heating they give off CO_2, when

cold and exposed to air they absorb the same gas.

Uniformity of Results

That uniformity of results is desirable is axiomatic. In order to produce uniform results it is necessary that the carburizing material be uniformly mixed. In a recent test conducted by the author carburizing boxes were made from 2-inch wrought iron pipe. These containers were approximately 6 inches long with a pipe cap forming the bottom. One and one half inch test specimens ⅜ inch in diameter were prepared from S. A. E. 1020 steel. Four test specimens were packed into the box, one in the bottom surrounded by chemical, the next one an inch above the chemical and surrounded by charcoal, the third 2 inches above the second and the fourth 2 inches above the third. The 3 upper specimens were surrounded by charcoal. The top of the box was luted tight with clay. An air space of ¼ inch was made above the chemical in the bottom and the screen which separated the charcoal from the chemical. Another pipe contained a thoroughly mixed compound and the last pipe contained pure wood charcoal. Reference to Table I shows that the specimen in the charcoal directly above the chemical showed the deepest case and had the highest carbon content. Other specimens directly above this one in the same pipe showed decreasing amounts of carbon. This was due to the fact that nearly all of the gas liberated by the chemical in the bottom of the pipe and converted to CO on contact with the hot charcoal passed the first specimen, while only some of it reached the specimen at the top of the pipe. Thus the specimen near the bottom of the pipe came into contact with a larger quantity of gas than did the others and consequently it acquired a higher carbon content. It seems to the writer that this is a good and sufficient argument for a thoroughly mixed carburizing material, regardless of whether the mixing is done by the user or by an outside manufacturer.

Decarburization

One of the most common commercial troubles is that of soft spots due to decarburization. This may possibly occur during long reheating in an open furnace preparatory to hardening. If there is an excess of air in the reheating furnace there would be a tendency for the carbon to be burnt out of the surface of the steel. However the danger of decarburization in commercial work is probably less than might be supposed. Figs. 8, 9, 11 and 12 show the same specimens before and after reheating for 30 minutes at 1400 degrees Fahr. in an open furnace. It will be noted that no decarburization is apparent on the specimens which were reheated.

Sometimes, however, decarburization occurs during the carburizing heat. A good example of this was observed by the author in which a specimen was carburized in a pipe containing pure wood charcoal. The ends of the pipe were sealed with a mixture of fire clay and sand. After slow cooling from the carburizing heat the specimen was sectionalized, polished and observed under the microscope. A broad band of almost carbonless iron at the surface was observed, followed by a zone containing about 0.60-0.70 per cent carbon. This can only mean that the steel was first carburized and then decarburized. As the pipe lay in a horizontal position in the furnace and as this specimen was crosswise in the pipe it is possible that toward the last of the heat, the end of the specimen observed became uncovered and consequently exposed to furnace gases which leaked in through the seal. It is universally recognized that when the carburizing material burns down and leaves the top pieces in the container exposed, that these pieces are liable to

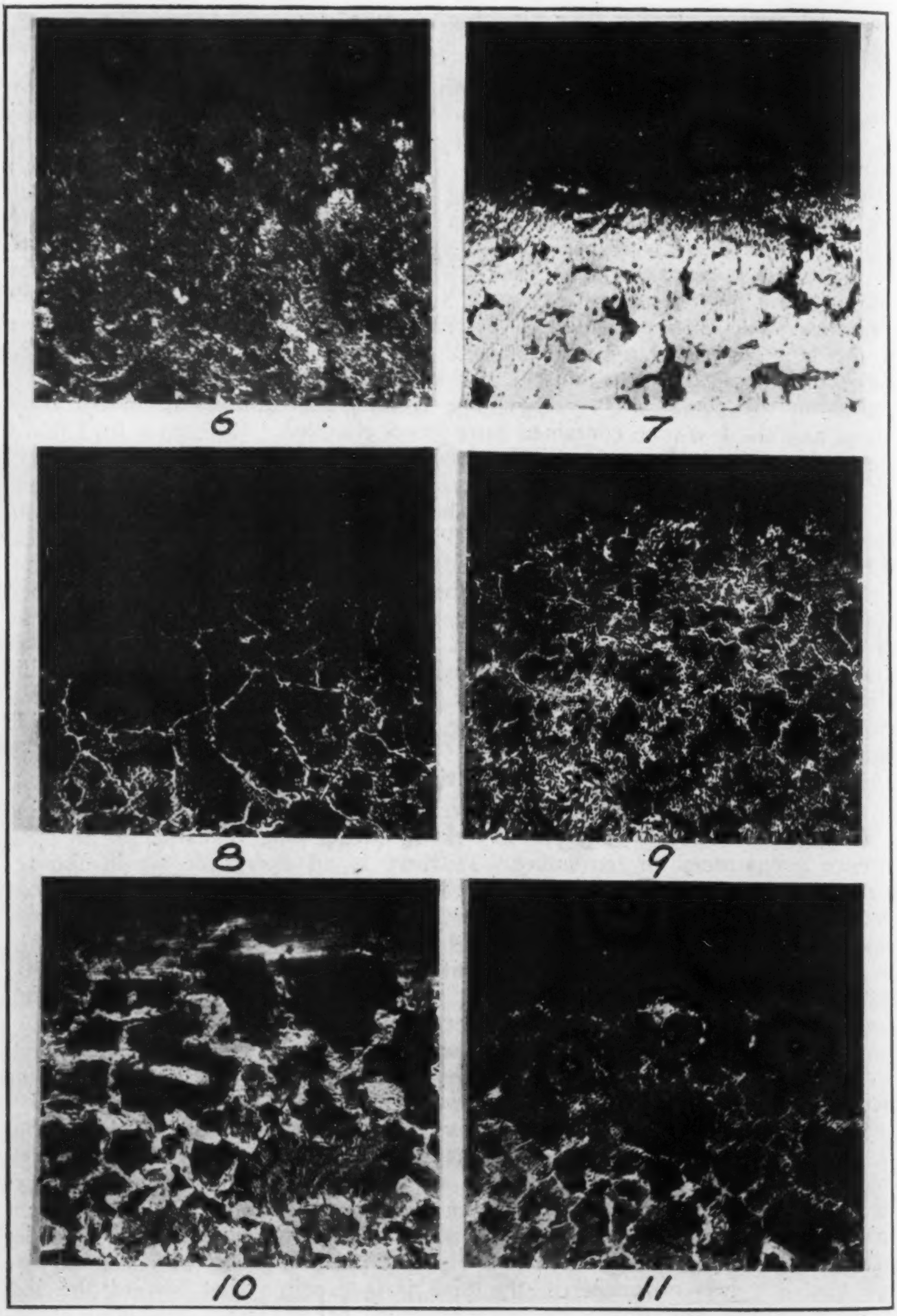


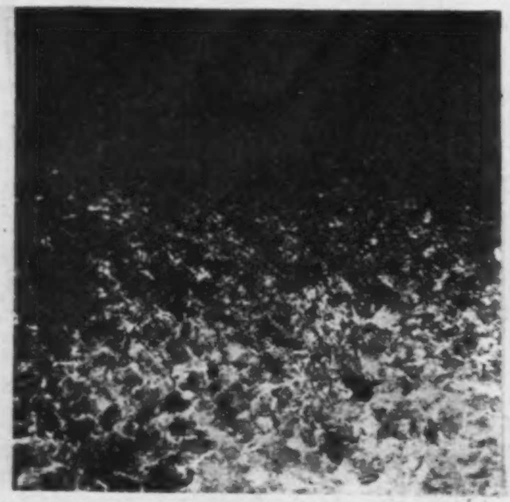
Fig. 6—Photomicrograph of bar in the center of pipe No. 2 containing used compound. X 150. Fig. 7—Photomicrograph of bar in the top of pipe No. 2 containing used compound. X 150. Fig. 8—Photomicrograph of bar in the center of pipe No. 3 containing new compound. X 150. Fig. 9—Photomicrograph of same bar as in Fig. 8, reheated for 30 minutes in an open furnace. X 150. Fig. 10—Photomicrograph of bar in the top of pipe No. 3 containing new compound. X 150. Fig. 11—Photomicrograph of bar in the center of pipe No. 4 containing wood charcoal. X 150.

become decarburized. However, it does not seem to be so commonly appreciated that pieces very near the top, but not actually uncovered, may be decarburized or at least very poorly carburized. In discussing decarburization it may be well to refer again to Giolitti. He shows that carburizing takes place according to the reversible reaction: $2\ CO = CO_2 + C$. Thus when the conditions are right the CO decomposes yielding carbon to the steel. But under other conditions CO_2 may actually absorb carbon from the steel. For any set of conditions of temperature, pressure, and concentration of gases there is a concentration of carbon in the steel which is in equilibrium with the system. If the conditions in the first part of the carburizing heat favor a high concentration of carbon in the steel, and the conditions at the end of the heat favor a lower concentration of carbon, a decarburization at the end of the heat would be expected.

Toward the end of long carburizing heats particularly when the compound has burned down considerably and the seal is not very tight, we would expect that the gas at the top of the pot or box would be largely CO_2. This would have a decarburizing action. A commercial example of this came to the writer's attention a year or so ago. A certain firm was complaining of soft spots on their finished work. These soft spots were still in evidence after the routine grinding operation. However it was found that on the grinding operation, most of the stock had been removed from one side and only a little from the side where the soft spots appeared. After grinding under-size, the soft spots disappeared. This was plainly a case of decarburization following carburization. An examination of plant conditions showed that the carburizing was done in large square boxes which had no lids. The tops of the boxes were covered with a mixture of fire clay and sand. Some of the boxes had been used for a long time and had large holes in the sides. These holes were also plugged with clay. The carburizing heat was run at 1700 degrees Fahr. for 10-12 hours. It is believed that these conditions were responsible for the decarburization.

Test Heat Showing Carburizing and Decarburizing Tendencies

In the preparation of this paper a test heat was run to show the carburizing and decarburizing tendencies. The data obtained in this test is shown in Table II and the photomicrographs are shown in Figs. 4 to 13 inclusive. In this test, 4 different carburizing materials were used; a 2 and 1 mixture old and new "compound"; all old compound; all new compound; and pure wood charcoal. The containers consisted of four 2-inch pipes with caps screwed on the bottom. The test specimens were 8 pieces of ⅜ inch diameter S. A. E. 1020 steel which were rough ground to remove scale and rust. One test specimen was placed horizontally 3½ inches from the top of each pipe, that is in the center of the pipe. Another test pin was placed 1¼ inches from the top of each pipe. After loading, the pipes were sealed with a mixture of fire clay and sand moistened with brine. The pipes were placed vertically and as close together as practicable in the center of the heated furnace. At the conclusion of the run the furnace was shut down and the pipes were allowed to cool in the furnace. The condition of the pipes and the seals may be seen in Fig. 2. It will be noted that the seals appear to be in good condition. Fig. 3 shows the same pipes after removing the clay. The per cent of shrinkage is given in Table II. The test specimens were sectionalized, polished, etched, and photographed through the microscope. In each case the photomicrograph shows the edge of the cross-section, that is they show the structure of the steel at the surface and for



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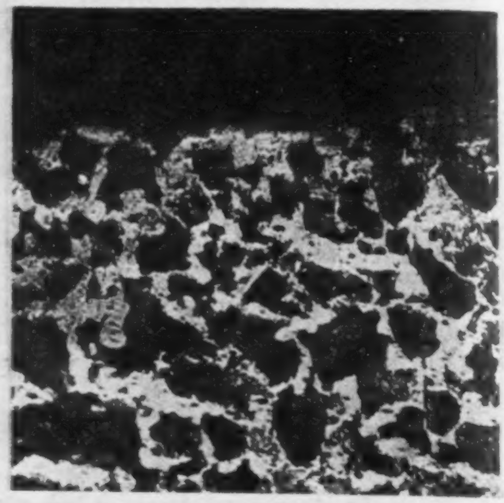

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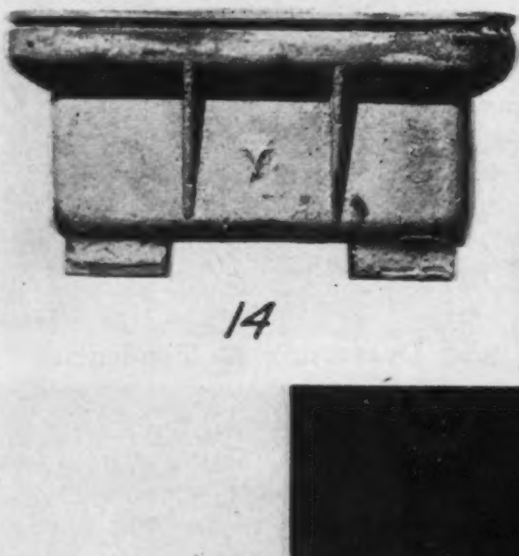

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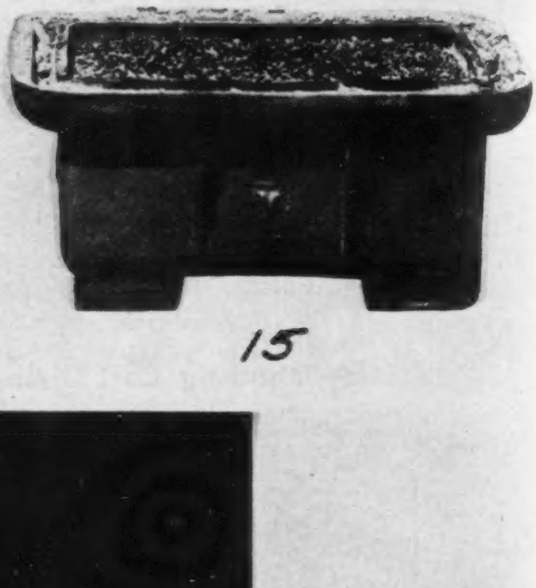

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Fig. 12—Photomicrograph of same bar as in Fig. 11 reheated for 30 minutes in an open furnace. X 150. Fig. 13—Photomicrograph of bar in the top of pipe No. 4 containing wood charcoal. X 150. Fig. 14—Photograph of carburizing box at the end of the heat. Fig. 15—Photograph of the same box after removing the lid. Note the small amount of shrinkage. Fig. 16—Photomicrograph showing the structure of bar carburized 1¼ inches from the top in the box.

about 0.01 inch below the surface.

Results

The data in Table II and the photomicrographs speak for themselves. It will be noted that the specimen in the center of each pipe shows a carbon content at the surface of eutectoid ratio or better, that is the carbon is 0.90 per cent or more. The specimen in the center of the pipe of new compound shows the highest carbon content being decidedly hyper-eutectoid. All of the specimens which were within $1\frac{1}{4}$ inches of the top of the pipes showed inferior carburization, being less than eutectoid ratio. All except the specimen in the top of the pipe of old material would harden fairly hard, and there

Table II

Data of Test Heat

Eight specimens of S.A.E. 1020 steel $1\frac{1}{2}$ inches long by $\frac{3}{8}$ inch in diameter rough ground and carburized for $6\frac{1}{2}$ hours at 1700 degree Fahr.

Pipe No.	Contents	Shrinkage by Volume	Position of Test Piece	Carbon Content At Surface	Photo Micrograph Figure No.
1	2 parts old 1 part new Compound	14 per cent	$3\frac{1}{2}$ inches from top	Eutectoid	4
			$1\frac{1}{4}$ inches from top	Less than eutectoid. Decarburized	5
2	All Used Compound	9 per cent	$3\frac{1}{2}$ inches from top	Eutectoid	6
			$1\frac{1}{4}$ inches from top	Almost no carburization	7
3	All New Compound	21 per cent	$3\frac{1}{2}$ inches from top	Hypereutectoid	8
			$1\frac{1}{4}$ inches from top	Less than eutectoid	10
4	All Wood Charcoal	34 per cent	$3\frac{1}{2}$ inches from top	Eutectoid	11
			$1\frac{1}{4}$ inches from top	Less than eutectoid	13

fractures would indicate a "case." These might easily pass a commercial inspection, but they would really be very inferior. The specimen in the top of the pipe of old material showed but very little more carbon than in the original bar. The specimen in the top of the mixture showed a tendency to decarburization at some spots. The moral of this would seem to be, to use a strong carburizing material and to keep the top pieces well below the top of the carburizing material. Placing them so that they do not become uncovered during the heat, is evidently not sufficient. Use of all new "compound" of the type used in this experiment, is not recommended for ordinary work as it seems to produce an excess amount of carbon, which might not be desirable.

Test with Tightly Sealed Carburizing Box

In order to determine the effect of increasing the efficiency of the seal, another test was run, using a commercial carburizing box with a specially designed lid which could be sealed tightly. This was loaded with a mixture of one part old and one part compound (same compound as used in the previous experiment). A test specimen was again placed $1\frac{1}{4}$ inches from the top. The heat was maintained at 1700 degrees Fahr. for $6\frac{1}{2}$ hours as before, and the box was allowed to cool in the furnace. The appearance of the box at the end of the heat is shown in Fig. 14. The appearance after removing the lid is

the heat is shown in Fig. 14. The appearance after removing the lid is shown in Fig. 15. It will be noted that the shrinkage is very much less, being about 6 per cent. The test specimen was sectionalized, polished, etched, and a photomicrograph taken at the edge of the cross section. This is shown in Fig. 16. There was a very thin layer of eutectoid composition at the surface. This does not show up as clearly as was hoped in the photograph, as the edge does not show up definitely. It may be considered therefore that this specimen is slightly better than those in the tops of the pipes. While the pyrometer record was very nearly the same in both cases, it is probable that the box being much heavier and thicker than the pipes, did not heat up nearly as fast as the pipes and consequently we could not expect as deep a case.

These tests were taken from a series of similar tests all of which seemed to follow the same general rule. It is believed therefore that the results may be taken as fairly indicative of the general principles and not merely as freak results.

Summary

Successful case hardening must produce a case of the proper depth, of the desired carbon content, and be free from decarburization. In order to be sure of producing the proper depth of case, it is recommended that a test piece be hardened and broken before pulling the heat. Carburization with solid materials is largely due to the action of CO. The concentration of carbon in the case, increases with the amount of CO. Carbon dioxide either inhibits carburization or causes decarburization. The conditions of carburization should favor as much CO and as little CO_2 as possible. Reheating in the open furnace if properly done should not cause excessive decarburization. All pieces to be carburized should be well below the surface of the carburizing material. Worn out or weak carburizers are not recommended. The carbon content is more easily estimated with the aid of the microscope than by examination of the fracture. Well sealed pots seem to be advantageous.

STUDY OF SOME FAILURES IN AIRCRAFT PLANE AND ENGINE PARTS

By J. B. Johnson and Samuel Daniels

This paper contains a compilation of several investigations made by the Material Section of the Engineering Division, Air Service, of breakages which have occurred in airplane and engine parts under service conditions. The investigation of failures is one of the most unsatisfactory duties of the testing engineer, as it is generally very difficult to determine definitely the cause of breakage. The conclusions which have been drawn were the best it was possible to deduce from the evidence submitted in the field reports and that obtained from the laboratory study of the broken specimens. Quite generally the history of the manufacture of the steel and the process of fabrication are not available, which adds to the complexity of the problem. There are, therefore, probably several points which are open to controversy, and it is hoped there will be free discussion of them.

The paper has been divided into three parts, each of which includes examples of failures which have been attributed to certain types of defects; but this classification is somewhat arbitrary, for often the investigation disclosed other contributing causes.

Part I

Failures Traceable to the Raw Materials

THE failures described in this section are attributed to improper selection of material or to defective steel which is generally caused by improper procedure in melting, casting, cropping, chipping, or other mill operations. Poor manufacturing practice leaves its mark commonly in the form of segregations, pipes, and seams, which are transmitted from the ingot or billet to the fabricated sheet, bar, or wire. Such defects decrease the available area of the stressed part and act as starting points for cracks in quenching, or determine at least in part the direction of the path of cracks, especially in a part subjected to vibration.

An example of the weakening influence of heavily segregated manganese sulphide is shown in Fig. 1, which represents a tachometer drive connection whose screw driver end was broken off in service. On the enlarged, roughly polished longitudinal microsection, Fig. 2, are lettered the fracture at *A*, and the transverse fissures *B*, *C*, and *D*. The annealed structure at the fracture was the same as that which existed at the borders of the transverse fissures. The steel contained 0.15 per cent of carbon and 0.114 per cent of sulphur, corresponding in composition to the S. A. E. screw stock specification No. 1114. Examination of the unetched surface at fissure *D*, Fig. 3 clearly

Acknowledgement is made to E. V. Schaal for part of the investigational work and to J. L. Hester for assistance in the photography.

A paper to be presented at the Detroit Convention, Oct. 2-7. Of the authors, J. B. Johnson, is Acting Chief, Material Section, War Department Air Service, McCook Field, Dayton, O. Samuel Daniels is metallurgist.

indicates that the cracks have followed the boundaries of manganese sulphide inclusions; and that when these particles were in the path of the progressing crack, they became more or less completely dislodged, with resultant widening of the breach. The stress which caused the failure was mainly torsional,

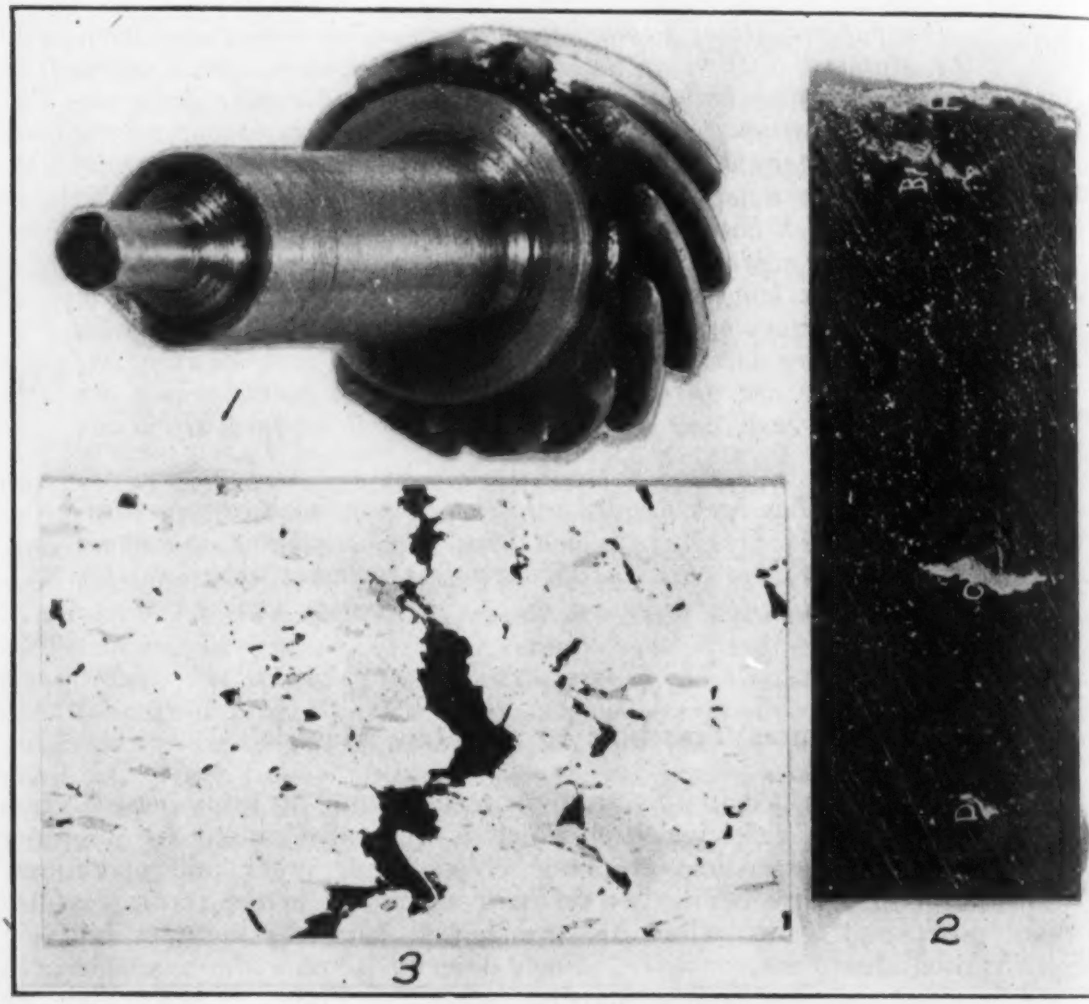


Fig. 1—Tachometer drive connection having failed in service. Fig. 2—Enlarged microsection of roughly polished portion of ruptured drive. Fractures are indicated as A, B, C and D. X 2. Fig. 3—Manganese sulphide inclusions responsible for failure of this component. X 100.

operating against the friction and especially the inertia of the tachometer and the flexible shafting when the engine speed was rapidly increased. The use of screw stock in such a part was not justified, and when S. A. E. steel No. 1020 was substituted the results were satisfactory.

Figs. 4, 5, 6 and 7 illustrate the extremely dangerous condition which resulted from the presence of a pipe in a forging billet. Fig. 4 is the transverse section, after light coarse-etching, of a pipe in a silico-manganese forged steel propeller, the analysis of which follows:

Carbon	0.55 per cent
Manganese	0.78 per cent
Sulphur	0.020 per cent
Phosphorus	0.016 per cent
Silicon	2.40 per cent

The structure was that of an annealed forging. A few surface cracks, caused by improper forging practice, had been filled with welding material and filed

smooth. The propeller broke in a whirling test, although the stresses were not excessive.

The transverse section of a piped clevis connection, Fig. 5, is to be seen in Fig. 6. This material passed the chemical and physical test requirements for cold-rolled S. A. E. steel No. 2330. The bar stock was machined into fittings. Later, when these were assembled in the airplane and the drift wires tightened in rigging the fuselage, one of the clevises broke. Other clevises

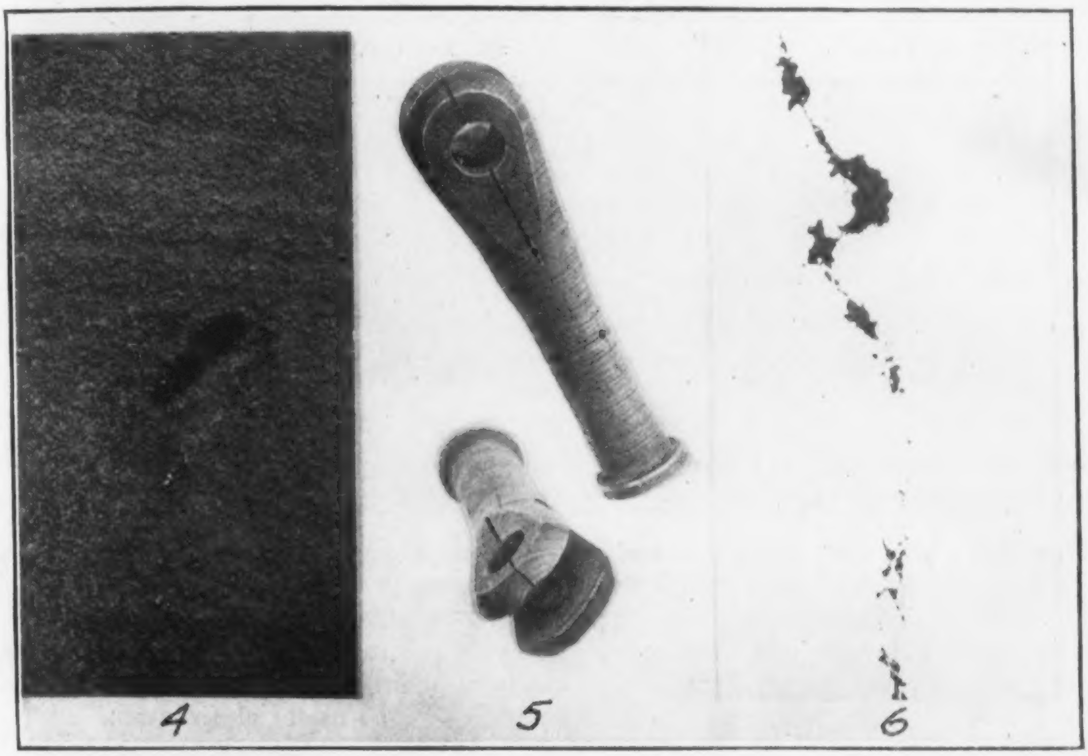


Fig. 4—Transverse section, after light deep-etching, of a piped silico-manganese forged steel propeller. X 2. Fig. 5—Rigging clevises which showed piping condition. Fig. 6—Pipe observed in clevises shown in Fig. 5. X 50.

from the same lot of material were immediately given a proof load test by applying 50 per cent of their rated load. In this test several of the clevises which had previously passed inspection, split longitudinally in tension, from the top of the clevis down through the eye.

Fig. 7, shows a valve which had been hand-forged from S. A. E. W-60a (high tungsten) steel. The stem of this valve had snapped off in service at the neck of the tulip, revealing a very spongy core, somewhat off center. Two longitudinal sections were prepared so that the one included most of the spongy area, and the other the sound portion. Upon coarse-etching the former and a piece of the stem in a boiling solution of 20 per cent aqueous sulphuric acid, the honeycomb through the neck and stem was brought out (Fig. 7, left), and in addition the discontinuity on both sides of the ring. The other half of the valve head was then etched in Humfrey's reagent (10 per cent cuprammonium chloride, 16 per cent concentrated hydrochloric acid, and 74 per cent of water (all by weight), for 75 minutes, after which immersion the section was freed from copper and then brightened by rubbing with 0000 emery paper. This etch also brought out the discontinuity (Fig. 7, right), the exact nature of which was not determined. One micro-section was

[1] Humfrey—Macro-etching and Macro-printing, Journ. Iron & Steel Inst.—1919, p. 273.

taken to include the break in macrostructure in this valve and another from the corresponding location in a tulip valve of like analysis which showed no differential attack in coarse-etching. It was impossible to detect great differences in microstructure between valves or on either side of the break. The structure of the neck side of the discontinuity is shown at 100 and at 1000 diameters in Fig. 8 and 9, respectively. In the latter metallograph an inclusion is to be seen, in addition to the undissolved carbides.

Pipes, practically closed up by the forging operation, were also found in a stainless, (S. A. E. 51230) high chrome steel valve as shown in Fig. 10.

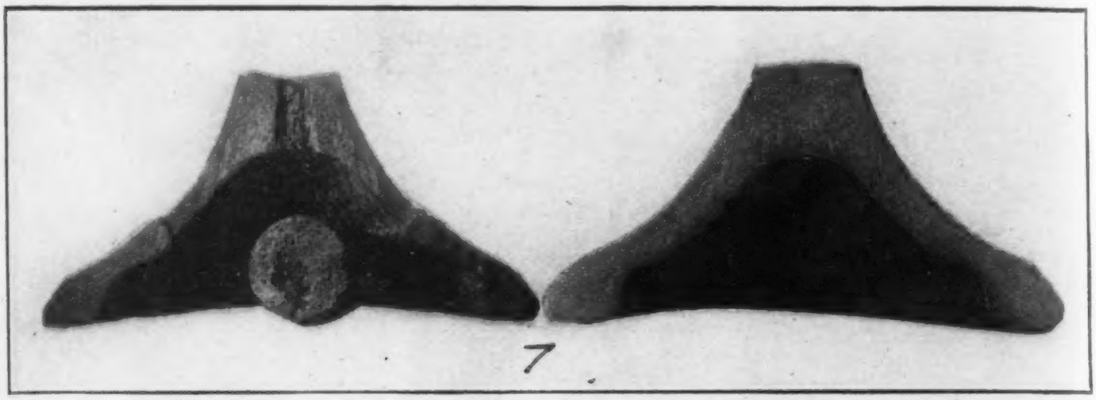


Fig. 7—High tungsten steel valve showing a spongy condition after deep-etching. X 0.9.

This valve was very unsound and snapped off abruptly at the neck, while in service.

The Air Service has had considerable trouble with seams in chrome-vanadium steel wire used for valve springs. A transverse section of one of these wires, revealing a seam whose width was one-third the diameter of the wire, is shown, Fig. 11. The partial analysis of this material follows:

Carbon	0.48 per cent
Chromium	1.02 per cent
Vanadium	0.15 per cent

The effect of the seam is augmented considerably by improper heat treatment. Such wire, incorrectly drawn, as indicated in Fig. 12, lasted only a few hours under repeated torsional stresses in the springs; but drawing at the higher temperature of 700 degrees Fahr., produced the structure shown in Fig. 13, with the result that the springs gave much better service. Their use, however, was limited to ground tests, and then only in case of emergency.

Part II

Failures Traceable to Poor Machining or to Design

The effect of such mechanical imperfections in the finished part such as tool marks, nicks, and sharp corners, is analogous to the effect from segregation of inclusions, pipes, and seams, inasmuch as they may be the starting points of hardening cracks or fatigue failures. The finest grade of crucible steel may reach the scrap pile by way of poor methods of machining.

Figs. 14, 15 and 16, show three clevises which failed in service. These connections carried the tension load of a vibrating wire. The failures occurred under normal flight conditions in airplanes which had been flown for a con-

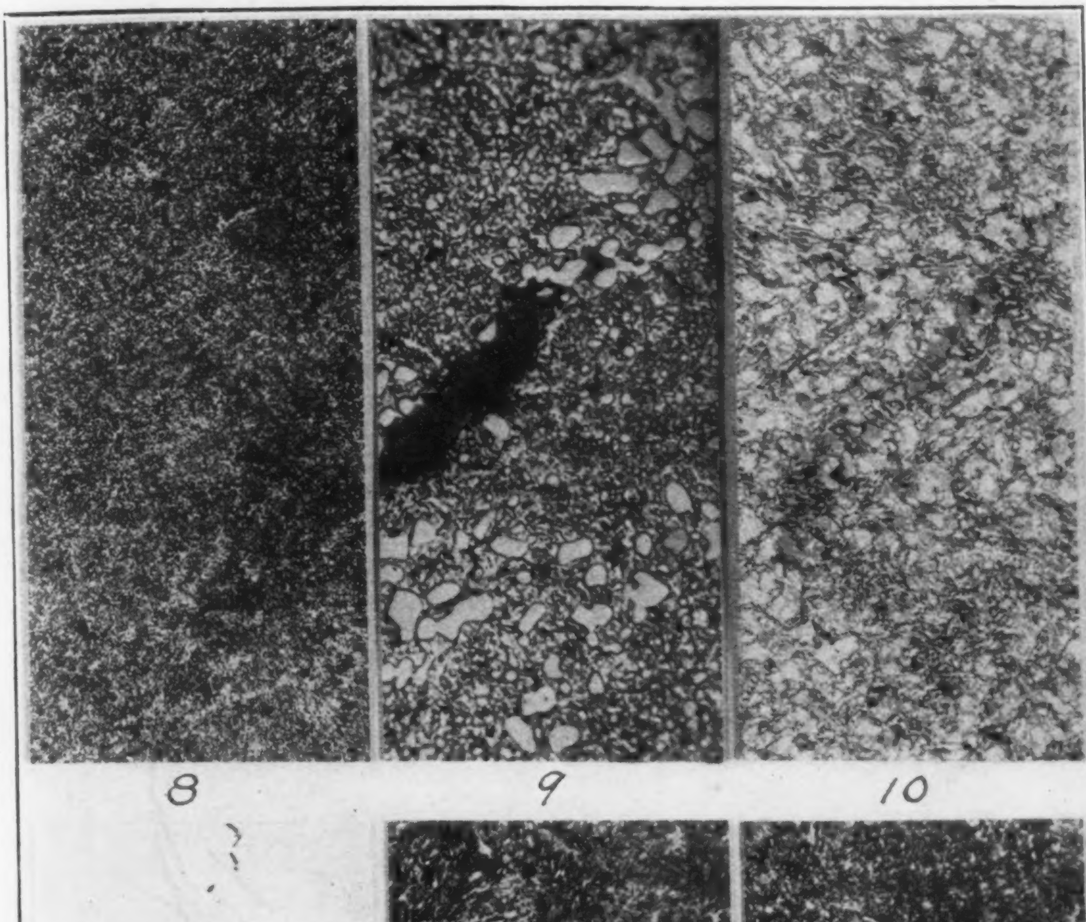
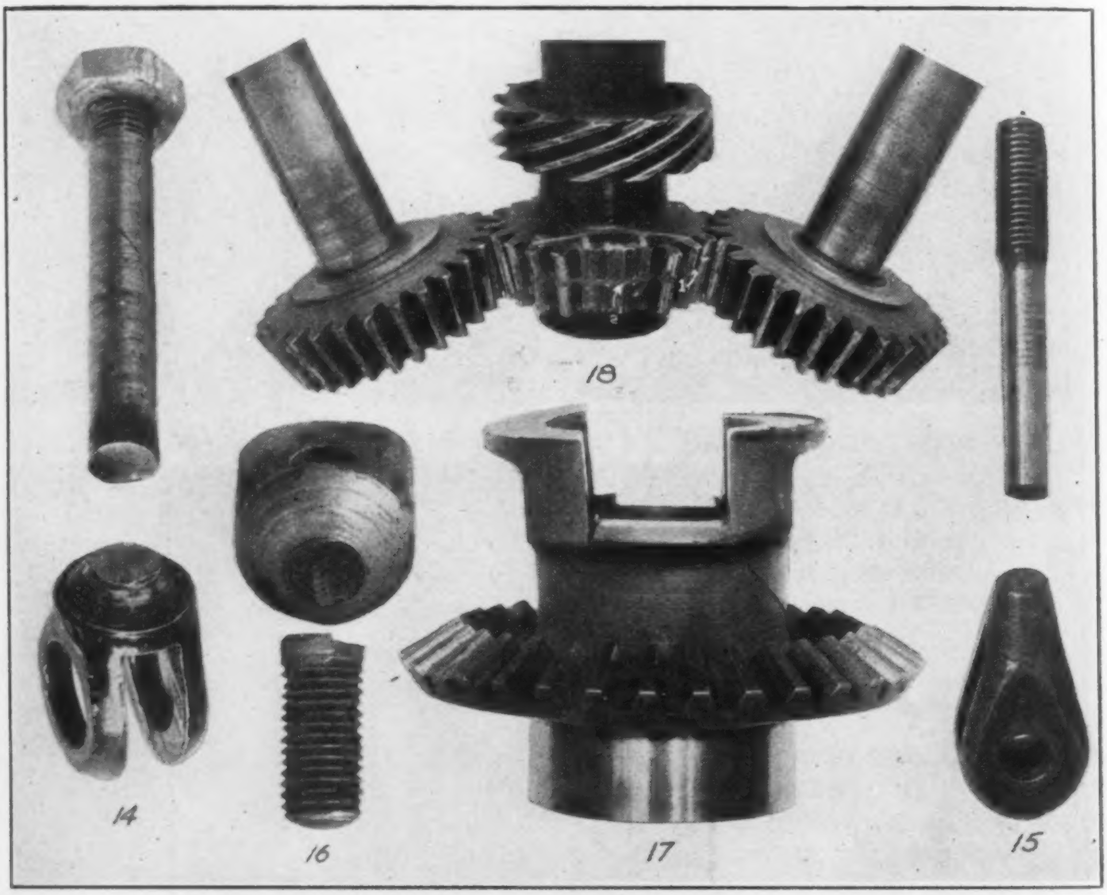


Fig. 8—High tungsten valve of Fig. 7. X 100. Fig. 9—Same valve at X 1000 showing undissolved carbide and non-metallic inclusion. Fig. 10—Stainless steel valve showing closed in pipe. X 11. Fig. 11—Seam which extended 1/3 thru Cr-Va valve spring wire. X 500. Fig. 12—Structure of same wire after improper drawing temp. X 500. Fig. 13—Same wire after proper drawing temp. X 500.

siderable period of time. Fracture developed at a point at the clevis end of the shank where the cross-section changed with only minor filleting and where there were deep tool marks, some of which are evident at other places along the shank. The steel in each case was found to be S. A. E. No. 2330 stock. The physical properties of the bolt were entirely satisfactory.

Ultimate strength, lb. per sq. in.	114,000
Yield point, lb. per sq. in.	101,000
Elongation in 2 in., per cent	22
Reduction of area, per cent	68.8

The results of a static tension test on ductile material are not influenced greatly



Figs. 14, 15 and 16 show three clevises which failed in service. These connections carried the tension load of a vibrating wire. Fractures developed at a point at the clevis end of the shank where the cross-section changed with only minor filleting and where there were deep tool marks. Fig. 17—Photograph of a failed crankshaft gear and starter coupling having sharp corners. Fig. 18—Gear failure which resulted from improper heat treatment and machining.

by small notches, but their effect on fatigue or shock resistance is considerable.

Sharp corners, too, are prolific as starting points for failures. In Fig. 17, is shown a photograph of a crankshaft gear and starter coupling manufactured from S. A. E. No. 2340 steel bar stock, the analysis of which is as follows:

Carbon	0.40 per cent
Sulphur	0.022 per cent
Nickel	3.61 per cent
Chromium	Nil

The coupling is subjected to considerable shock and must be hard. The

Brinell hardness of this part, taken near the fracture, was 555 and the scleroscope 65. The question arose as to whether the absence of proper filleting, or, in the light of experience with other gears not subjected to like shock, the abnormal hardness of the part was more important in causing the rupture. Exactly the same situation obtained with a Liberty crankshaft gear of S. A. E. No. 2340 steel, but of a Brinell hardness of 600. That a nickel steel is suitable for these parts is controvertible; and in fact, S. A. E. No. 3240 steel was recommended, as this steel will give greater ductility and shock resistance than the No. 2340 steel for the same Brinell hardness. The Brinell hardness range specified for the ordinary run of gears is from 400 to 440, and these

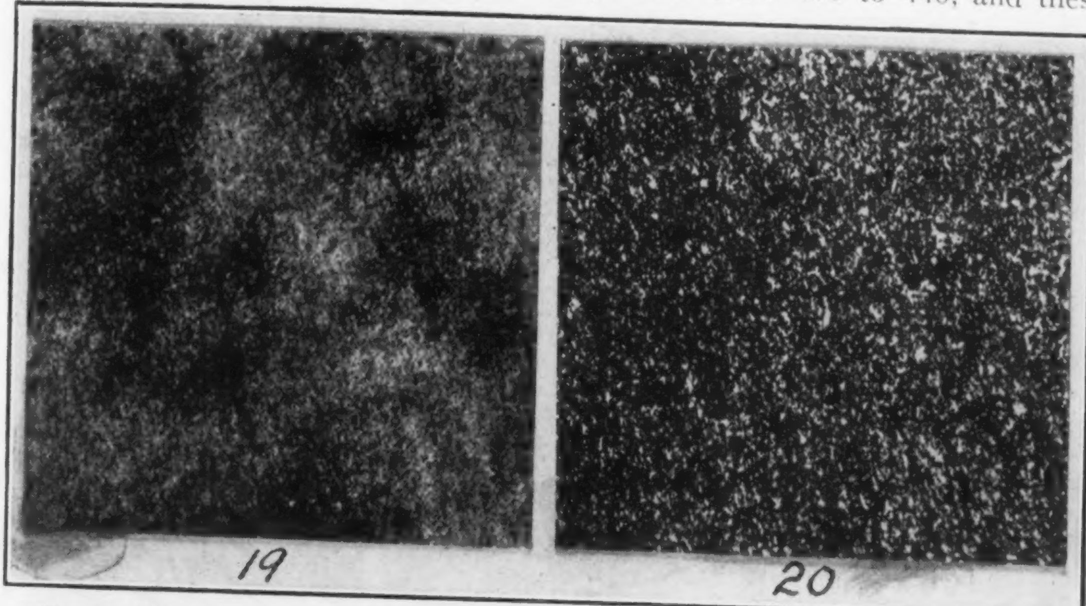


Fig. 19—Photomicrograph of banded structure observed in the ruptured gear of Fig. 18. Fig. 20—Photomicrograph showing homogeneous structure resulting from a proper treatment of gear shown in Fig. 19. Both photomicrographs. X 100.

limits were tentatively set for the gear parts described above, with the additional requirement of fillets at least one-sixteenth inch in radius.

Part III

Failures Traceable to Improper Heat Treatment

The number of failures directly attributable to improper heat treatment has been increasing rapidly. Disregard for the laws commonly adhered to in scientific metallurgical control and neglect to accurately follow the specifications given, have often resulted in unsatisfactory contract work. The situation has led to much closer supervision, during the heat treatment, by the Air Service inspectors.

The train of gears shown in Fig. 18, failed before the completion of a 50-hour dynamometer test run. The chemical analysis of the central camshaft driving pinion was as follows:

C .35, Mn .58, S .042, P .006, Cr 1.04, Va .23.

The Brinell hardness of this part was 402. Examination revealed that sharp corners existed at the roots of the teeth. Despite the fact that the Brinell hardness was suitable, and that no fillets had been provided, the principal reason for the failure was attached to improper heat treatment. The banded structure of Fig. 19, taken of the gear as received, has been frequently observed in failed gears of this analysis; but no failures have yet been recorded of gears treated to the homogeneous structure represented in Fig. 20, which

was obtained by soaking the banded specimen for 30 minutes at 1675 degrees Fahr. and quenching in oil, followed by a draw at 650 degrees Fahr. in a nitrate bath.

An examination of a broken propeller hub cap which had failed in service, illustrated the effect of improper structure. This component is a hollow cylindrical piece machined from a hot-pierced forging of S. A. E. No. 1045 steel.

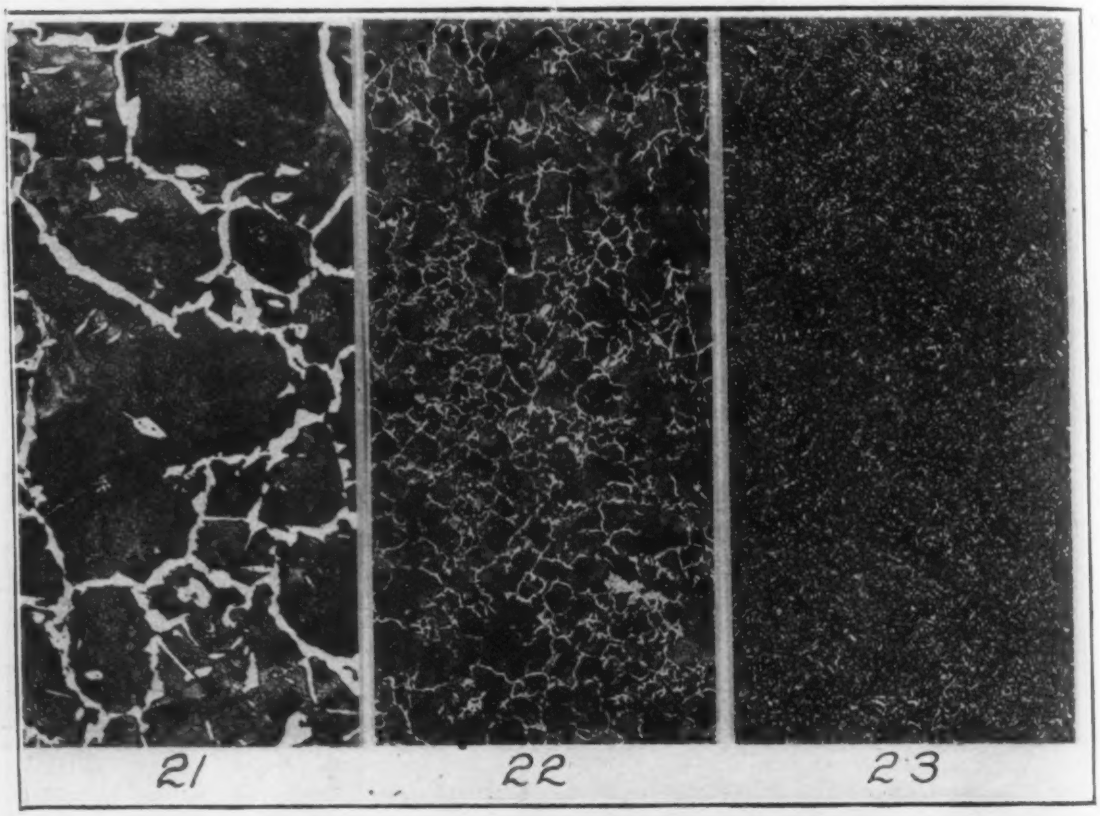


Fig. 21—Photomicrograph of broken propeller hub cap which failed in service. This coarse-grained hypoeutectoid structure has poor resistance to shock. Figs. 22 and 23—Photomicrographs of the same material shown in Fig. 21, heat treated to obtain increased impact resistance. X 100.

The primary stresses in service are tension and compression exerted by the centrifugal force of the blades, and bending caused by thrust. The loads are suddenly applied by rapid acceleration of the engine. The microsection from the broken cap revealed a coarse-grained hypoeutectoid structure similar to that in Fig. 21. Tension test specimens cut from the broken hub gave the following results:

Ultimate strength, lb. per sq. in.	97,630
Yield point, lb. per sq. in.	59,800
Elongation in 2 in., per cent	19.2

Another hub cap from the same lot was then selected for the purpose of improving its shock-resisting qualities, which were believed to be low, even in the light of the rather good tensile properties developed by the first forging tested. The properties of the steel for the heat treatments selected for trial

are given in Table I. On account of the marked increase in impact resistance which it produces in the steel, the treatment prescribing quenching and drawing was recommended for the part and has been used successfully. The metallographs (Fig. 21, 22 and 23) illustrate clearly the changes in grain size and structure which accompanied the marked improvement in yield point, ductility, and impact resistance.

A hardening crack, which started in a sharp corner, was the cause of failure of an improperly heat treated master connecting rod which came

Table I
Physical Properties Resulting from Different Thermal Treatments

Structure	As forged Sorbite plus ferrite network	Annealed* Sorbite plus ferrite network	Quenched and drawn** Sorbite
Ultimate strength, lb./sq. in.	99,260	107,720	100,830
Yield point, lb./sq. in.	41,760	60,610	84,710
Elongation in 2 in., per cent	19.5	21	26
Reduction area, per cent	30.8	44	61.7
Brinell	192	211	207
Scleroscope	31	35	35
Izod impact (V notch)	2.3	12.5	43.3
Charpy impact (round notch)	7.8	11.5	50.2

* Soaked at 1525 degrees Fahr. for 20 minutes and cooled in air.
** Soaked at 1525 degrees Fahr. for 20 minutes, quenched in water, and drawn at 1200 degrees Fahr.

Chemical Analysis

Carbon	0.52	per cent
Manganese	0.58	per cent
Phosphorus	0.032	per cent
Sulphur	0.026	per cent

under observation. The rod had run about 100 hours with the engine operating at normal horsepower. The smooth, fan-shaped fracture, proceeding from the sharp corner, indicated that this portion was progressively opened up by fatigue stresses; while the fibrous condition beyond marked the plane of ultimate rupture induced by both shear and bending forces. The chemical analysis was normal for an S. A. E. No. 6135 steel:

Carbon	0.35	per cent
Manganese	0.59	per cent
Sulphur	0.022	per cent
Phosphorus	0.030	per cent
Chromium	0.86	per cent
Vanadium	0.13	per cent

The average Brinell hardness of 230 was somewhat lower than the value obtained in properly treated connecting rods. Heterogeneity of metallographic structure, evident in Figs. 25 and 26, is the result of different rates of cooling in the heavier section (crank end) at the fracture, and in the web of the lighter I-beam section (piston-pin end), respectively. Both structures are very finely sorbitic, with free ferrite, the latter constituent being more abundant at the fracture, where the rate of cooling was slower. These structures are typical of air-cooling from above the critical range. It was found impossible to duplicate either structure in a specimen which was oil quenched from 1650 degrees Fahr., reheated to 1350 degrees Fahr., and air-cooled. It seemed probable that after forging, the connecting rod was quenched in oil from about 1650 degrees Fahr., and then air-cooled at a temperature approximating 1475 degrees Fahr., thus accounting for the fine grain size of the

material (Fig. 24). The proper structure for this part, obtained by quenching from 1650 degrees Fahr. in oil and drawing at 1140 degrees Fahr., following normalizing and annealing, is shown at 1000 diameters in Fig. 27. It was suggested that a change in design be made to include ample fillets, thus to lessen the danger of hardening cracks and the localization of fatigue stresses.

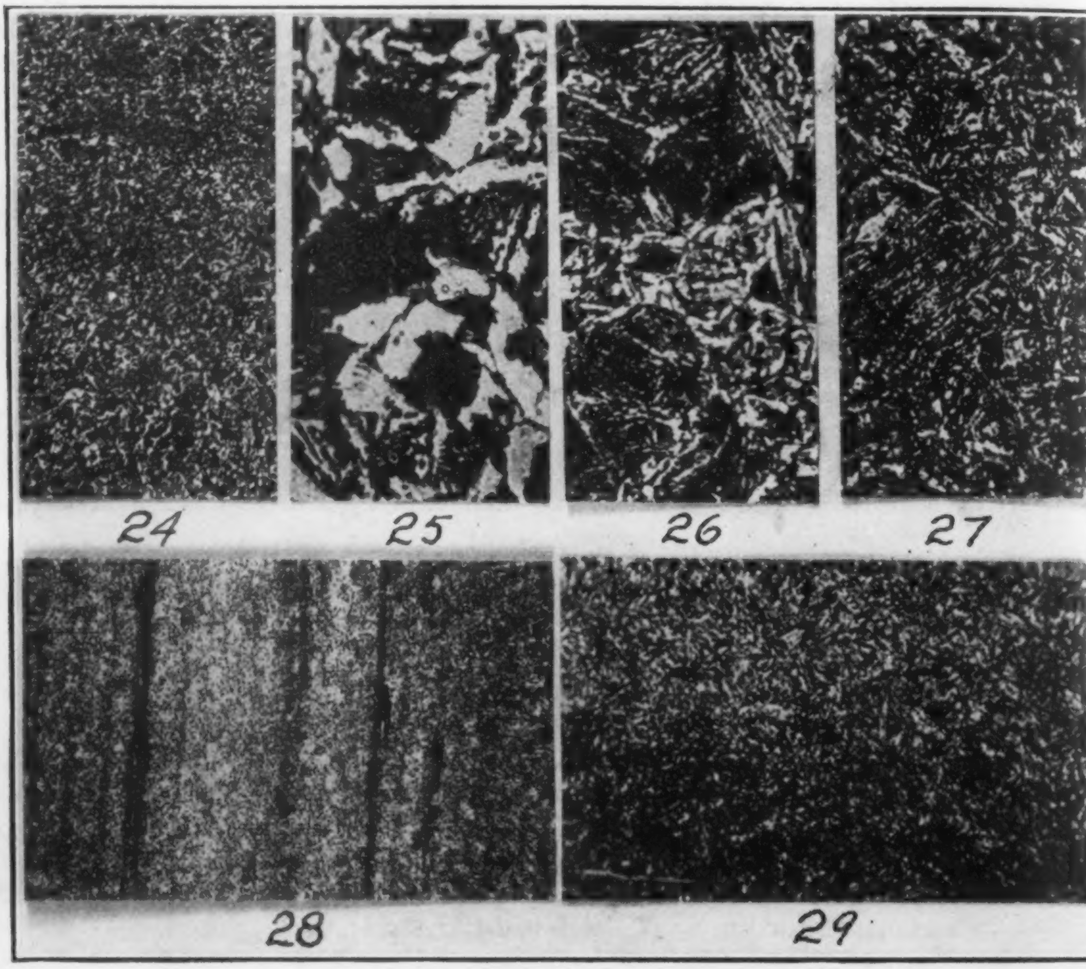


Fig. 24—Photomicrograph of connecting rod quenched in oil from 1650 degrees Fahr. and air cooled from a temperature of 1475 degrees Fahr., thus accounting for the fine grain size. X 100. Figs. 25 and 26—Heterogenity of metallographic structure resulting from different rates of cooling connecting rod. Fig. 25 shows the structure in the heavier section (crank end). X 1000. Fig. 26 shows the structure in the thin section (piston-pin end). X 1000. Fig. 27—Photomicrograph at 1000 diameters showing the proper structure for this component when quenched in oil from 1650 degrees Fahr. and drawn at 1140 degrees Fahr.

Fig. 28—Photomicrograph of ghost-lines present in ruptured valve springs. Several of these springs failed to withstand a 180-degree bend test. X 100. Fig. 29—Photomicrograph at 1000 diameters showing a sorbo-troostitic structure.

In another case a number of valve springs broke in a service run. The analysis was found to be the following:

Carbon		0.52 per cent
Manganese		0.96 per cent
Sulphur		0.025 per cent
Phosphorus	less than	0.030 per cent
Chromium		1.30 per cent
Vanadium		0.28 per cent

Several of the springs failed to withstand a 180-degree reverse bend, and

(*Continued on page* 1212)

IRREGULARITIES IN CASE HARDENED WORK CAUSED BY IMPROPERLY MADE STEEL

By E. W. Ehn

Abstract of Paper

1. *Failure in case-hardening, especially in reference to soft spots, is often due to improper steel. Variation of structure of a carburized piece gives a direct indication whether the steel is suitable for carburizing or not.*

2. *Coarse-grained structure in case and core of carburized steel with large crystals of pearlite, and clean cut cementite areas in the hyper-eutectoid zone, are signs of good or normal steel. Curly cementite, disintegration of pearlite in hyper-eutectoid zone, and fine-grain size with rounded pearlite areas in the gradation zone and core are signs of an abnormal steel. Abnormal steel has a tendency to give a thin case of high-carbon content and to form soft troostitic spots in hardening.*

3. *The structure of normal and abnormal steel varies with the carburizing temperature and the rate of cooling. Carburizing tests on a laboratory scale can easily be made.*

4. *The variation in carburizing properties is caused by oxides uniformly distributed in solid solution in the steel. The ultimate cause is improper deoxidation of the steel when made, and no later treatment can change these properties.*

5. *The influence of the oxides in regard to grain size is theoretically explained by their influence on the solidification of the steel in the ingot and their later obstructing action against grain growth. Disintegration of the pearlite in the hyper-euctectoid zone is caused by the solution pressure from the oxides in solution in the ferrite.*

6. *The formation of soft troostitic spots in hardening of abnormal steel is explained by the action of the oxide particles as starting points for the troostite formation. This explanation is founded on the investigations of Portevin and Garvin on hardening of carbon steels.*

7. *The results obtained in heat treatment of all kinds of steels, notably high and medium carbon steel, is dependent on the presence of oxides in the steel, and many mysterious failures, especially in hardening, are likely to find their explanation by carburizing; and a microscopical examination of the structures obtained.*

The experiences given in this paper are the results of considerable research work during the last few years in the Metallurgical Department of The Timken Roller Bearing Company. Most of these results have already been published (H. W. McQuaid and E. W. Ehn "Effect of Quality of Steel on Case Carburizing Results"—American Society of Mining & Metallurgical Engineers, February, 1922, and E. W. Ehn—"Influence of Dissolved Oxides on Carburizing and Hardening Qualities of Steel"—Iron & Steel Institute, May, 1922), and it was only after request from the Publication Committee for the Detroit convention meeting of the American Society for Steel Treating that the present paper was prepared. This remark is made because the writer wants it understood that he has drawn freely on the previous papers and that this paper does not contain any materially new information, although a few new experiences are included.

A paper to be presented before the Detroit Convention October 2-7. The Author E. W. Ehn is metallurgist, Timken Roller Bearing Co., Canton, Ohio.

Introduction

IN CARBURIZING steels of similar chemical compositions, similar results are generally expected and if the carburizing and hardening are properly conducted, satisfactory results are anticipated. This paper will show that the quality of steel when made, has a very material influence on the results obtained in carburizing and hardening, and that satisfactory results can only be obtained with carefully made and deoxidized steel. The trouble experienced with inferior grades of steel are mainly the occurrence of soft spots after the hardening operation and sometimes, although comparatively seldom and only in the worst types of steel, shallow and uneven carbon penetration resulting from the carburizing process.

The paper will, unless otherwise stated, deal with steel of the following composition:

Carbon	.15 to .20 per cent
Manganese	.35 to .65 per cent
Phosphorus	below .040 per cent
Sulphur	below .040 per cent
Silicon	.05 to .20 per cent

It will be shown that some steels although in accordance with this analysis, which can be regarded as a standard for plain carbon steel for carburizing, are entirely unsuitable for carburized parts and cannot be used without grave danger of inferior results. This is, moreover, not only a question of theoretical interest but a matter of great commercial concern, as this condition in steel is far more common than is usually suspected. In the plant with which the writer is connected hundreds of tons of steel have had to be diverted to other purposes than carburizing and thousands of dollars worth of half finished work scrapped owing to failure in hardening. It can be said that as a rough estimate about 25 per cent of all steel bought in the open market has been found to be unsuitable for carburizing and it has been found necessary to institute very careful checking of every heat of steel before allowing it to be used for production.

The plant with which the writer is connected is the maker of tapered roller bearings. In making of the different parts of these bearings, which are all made of case-hardened low carbon steel with and without alloying elements, depending on the service they will be exposed to, it is of utmost importance that uniformity in depth of case and hardness be obtained. In the hardening department of this plant it would occasionally happen, in spite of extreme care in the different operations, that a large amount of carburized work would fail to harden properly and had to be rejected on account of soft troostitic spots. These failures were at first attributed to faulty carburizing or hardening practice, but after considerable research work it was definitely proved, that the cause was due to some inherent property in the steel itself. The failures in the hardening were always traced to certain lots, while other lots that had simultaneously undergone the same processes gave no trouble whatever. Different carburizing compounds and different methods of quenching were tried, but failed to improve the results, and by gradually working back through the different stages of conversion of the steel, it was finally proved that the carburizing and hardening qualities of the steel were inherent in the ingot itself, and remained unchanged in any way by different operations in the course of manufacture.

It was also found that this feature of soft spots in the case hardened

steel was always combined with a special fine grained structure in the carburized parts. Steels which on hardening in water acquire a uniformly hard martensitic case will in what follows, be referred to as normal, whereas steel giving soft spots in the hardening will be called abnormal.

Part I

Microstructure and Properties of Normal and Abnormal Steel Observed Under Operating Conditions

The carburizing referred to in this part have been done in hydro carbonated bone-black at 1675 to 1700 degrees Fahr. followed by a cooling of the pots in the air. The carburizing compound used is, however, of no material importance except in relation to the maximum carbon content that it will transmit to the carburized pieces, and in order to develop clearly the difference in micro-structure between normal and abnormal steel, it is desirable that the carbon content of the hyper-eutectoid zone be 1.05 per cent or more. The hydro carbonated bone-black is a comparatively slow compound and so blended that a case of eutectoid or slightly hyper-eutectoid composition is obtained at least in case of less than 0.040 inch in depth. Most of the photomicrographs are therefore taken from samples with greater depth of case or in some cases from specimens that purposely have been carburized in more energetic compounds in order to conform with this condition.

A microscopical examination of carburized work reveals a large number of different types of micro-structures usually fairly uniform in parts made of steel from the same lot but varying greatly with different lots. Figs. 1 and 2 show typical structures of normal and abnormal steel after carburizing. The first steel will harden without difficulty and give a uniformily hard martensitic case, whereas the other is likely to give soft troostitic spots in hardening. The characteristics of the different structures of the different parts of the case will be better understood from separate photomicrographs at higher magnification taken from specimens other than those that were used in Figs. 1 and 2.

Extreme Cases of Normal and Abnormal Steels

Hyper-Eutectoid Zone.—Figs. 3 and 4 show the extreme types of normal and abnormal steel. In the normal steel the hyper-eutectoid zone (Fig. 3) consists of pearlite and free cementite sharply defined at the grain boundaries or lying as needles throughout the mass of the crystals. The grains are generally large and sharp-cornered in outline. The hyper-eutectoid zone of very abnormal steel (Fig. 4) consists of pearlite, cementite, and free ferrite. The cementite lies as small curly fragments in a mass of ferrite formed by the more or less complete divorce of the pearlite. The outlines of the crystals are not well defined, they do not follow straight lines, and the crystal size is small as compared with the normal steel. In order to develop this structure clearly it is necessary that excess cementite be present, the more the better, and the most pronounced types of this structure are therefore obtained in the corners of the specimens, where an almost complete divorce of the pearlite can sometimes be obtained.

Eutectoid Zone.—The difference is, at least in commercial steels, not very pronounced, but some cases have been observed where the abnormal steel shows a somewhat "fiery" appearance, with a more coarsely lamellar

pearlite than in the normal steel.

GRADATION ZONE.—The structure in the gradation zone is very sensitive to any variation in the steel, and the difference in structures obtained is even more pronounced than in the hyper-eutectoid zone. This is especially important in an eutectoid case, where the absence of excess cementite prevents the formation of the typical structure of the hyper-eutectoid zone, although it must be noted, that the structure of the gradation zone is more dependent on the carburizing temperature and the rate of cooling than that of the hyper-eutectoid zone. The normal structure in the gradation zone (Fig. 5) is considered as triangular or at least sharp-cornered areas of pearlite with sides not less than ½ inch at 100 diameters magnification and separated by clearly defined ferrite lines. The abnormal structure (Fig. 6) consists of rounded, not so well defined, and much smaller areas of pearlite often located in a streaky way. Between these two extreme types all kinds of intermediate structures are obtained with different steels.

CORE.—The difference is similar to that obtained in the gradation zone. Figs. 7 to 10 show normal and abnormal steel before and after carburizing. Before carburizing the structure of the two steels is very similar, but after carburizing the grain size in the normal steel has grown, as might be expected after a prolonged heating around the Ac_3 point, whereas the abnormal steel shows an actual decrease in grain size. The pearlite in the normal steel forms comparatively large shorp-cornered areas, whereas the pearlite areas in the abnormal steel are rounded, much smaller and not so well defined in outline.

A difference in structure of the same kind would of course have been produced by an anneal at the same heat, and this accounts for the difference in structure that is sometimes observed in low-carbon steels after having been submitted to a normalizing anneal around 1700 degrees Fahr. Although somewhat beside the subject under discussion, the writer wants to call attention to the importance of these different properties in steel, when machine parts are subjected to tough anneal and similar heat-treating operations, and the similarity in the problem of securing a steel with good carburizing qualities and steels that will respond readily to other kinds of heat treatment.

This difference in grain size disappears with the employment of higher temperatures, as will be shown later. This fact accounts for the similarity in structure of normal and abnormal steel before carburizing, as, for the different operations in the steel mill, considerably higher temperatures are employed. The only case when it is possible to determine in advance the carburizing qualities is when the steel is banded and filled with ghost-lines. A steel of this kind is likely to show abnormal carburizing qualities, but even this is by no means a certainty.

Steel With Intermediate Properties

The structures described above are to be regarded as the extreme limits that can be expected in commercial steels. Both of these types are comparatively scarce, and the great majority show structures between these two limits approaching one or the other. It is indeed possible to obtain a complete sequence of structures that gradually, with small changes, cover the entire field between normal and abnormal structures, and the experience has been that with this change in structure there is simultaneously a change in the way the steel responds to the hardening operation. This change in structure is perceptible both in the case, the gradation zone and the core, but is most

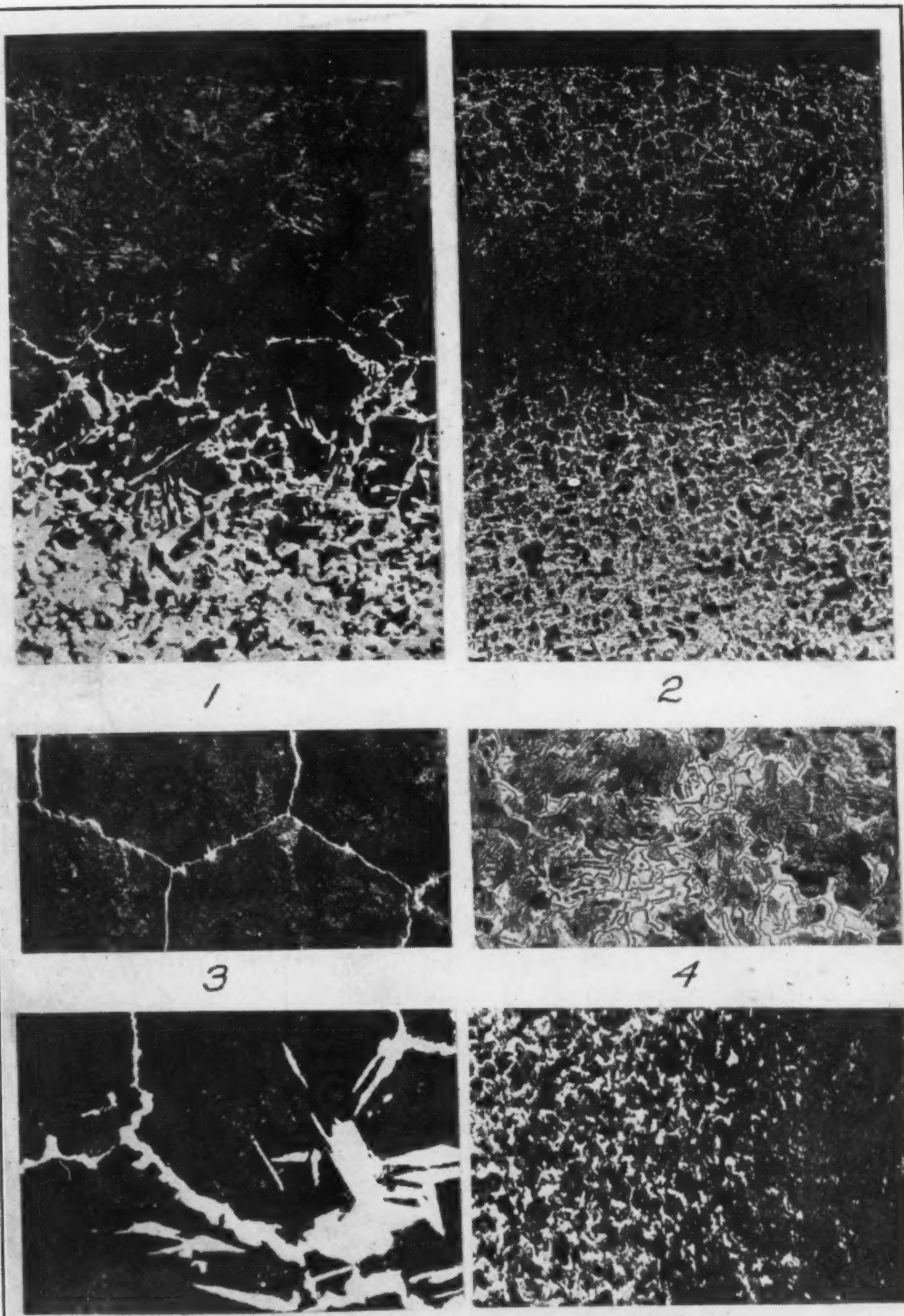


Fig. 1—Case of normal steel. Will give a martensitic case in hardening. X 50. Fig. 2—Case of abnormal steel. Will give soft troostitic spots in hardening. X 50. Fig. 3—Hypereutectoid zone of normal steel. X 200. Fig. 4—Hypereutectoid zone of abnormal steel. X 200. Fig. 5—Graduation zone of normal steel. X 100. Fig. 6—Graduation zone of abnormal steel. X 100.

clearly visible in the hyper-eutectoid zone and only photomicrographs from this zone are, therefore, given in description of these steels. The change in the gradation zone is toward pearlite areas with rounded outlines instead of angular, and with increasing abnormalty also a diminishing of the grain size.

The change in the hyper-eutectoid zone starts with the cementite changing from straight lines to lines with knotty appearance as in Figs. 11, 12 and in somewhat more advanced cases, also with an irregular and smaller grain size as in Figs. 13 and 14. In perfectly normal steel the cementite is often found as perfectly straight needles through the crystals but in slightly abnormal steel the needles are knotty and interrupted with an appearance such as shown in Fig. 15. This tendency of the cementite to be precipitated as needles is different in different steels, but just exactly what conditions cause this phenomenon, the writer is unable to state. That a high temperature will cause this structure is above doubt (Figs. 35 and 36) but the writer believes that the deciding factor at usual carburizing temperatures is some inherent property in the steel itself rather than the rate of cooling, an opinion that seems to be prevailing in the literature.

The above types constitute the limit where a successful hardening can be accomplished. The next steps are shown in Figs. 16 and 17, where the grain size is still smaller and the cementite is no longer present as continuous lines but as more or less curly and knotty fragments.. A starting divorce of pearlite is often noticed in this type. Still more pronounced abnormal structures are shown in Figs. 18 and 19, both of which can be regarded as absolutely hopeless in regard to hardening and which never should be used for case-hardening purposes.

A different type of structures that does not fit in well in the above series is a type where the grain size is fairly large but the cementite is surrounded by ferrite from a partial disintegration of the pearlite as shown in Fig. 20. This type of steel gives very poor results in hardening with a tendency to form soft spots, which contrary to the usual types of abnormal steel with fine grain size after hardening, results in a coarse and "fiery" fracture. Another type contains abnormal and normal parts intimately mixed in the same section throughout the case and the core as in Fig. 21. This structure is regarded with great suspicion as an indication that other parts of the steel might be of unmixed poor quality.

Variation in Depth of Case and Maximum Carbon Content Caused by the Steel

Several authors when writing of carburizing give detailed and exact figures as to the depth of case and the maximum carbon content that will be obtained with different carburizing reagents and different temperatures. How they have been able to obtain these figures down to 0.001 inch is a mystery to the writer, as it is hardly possible to obtain the depth of case with a microscope closer than within 0.005 inch, and even to obtain figures of this accuracy personal judgment is necessary. The depth of case is seldom exactly the same all around a piece, and two pieces carburized close together in the same pot often show a difference of as much as 0.005 inch, which of course is of no commercial importance, but nevertheless true in spite of all the claims to the contrary made by agents for different carburizing compounds.

In regard to the influence of the steel on the depth of case, the writer could give figures from carefully recorded tests on a laboratory scale, but

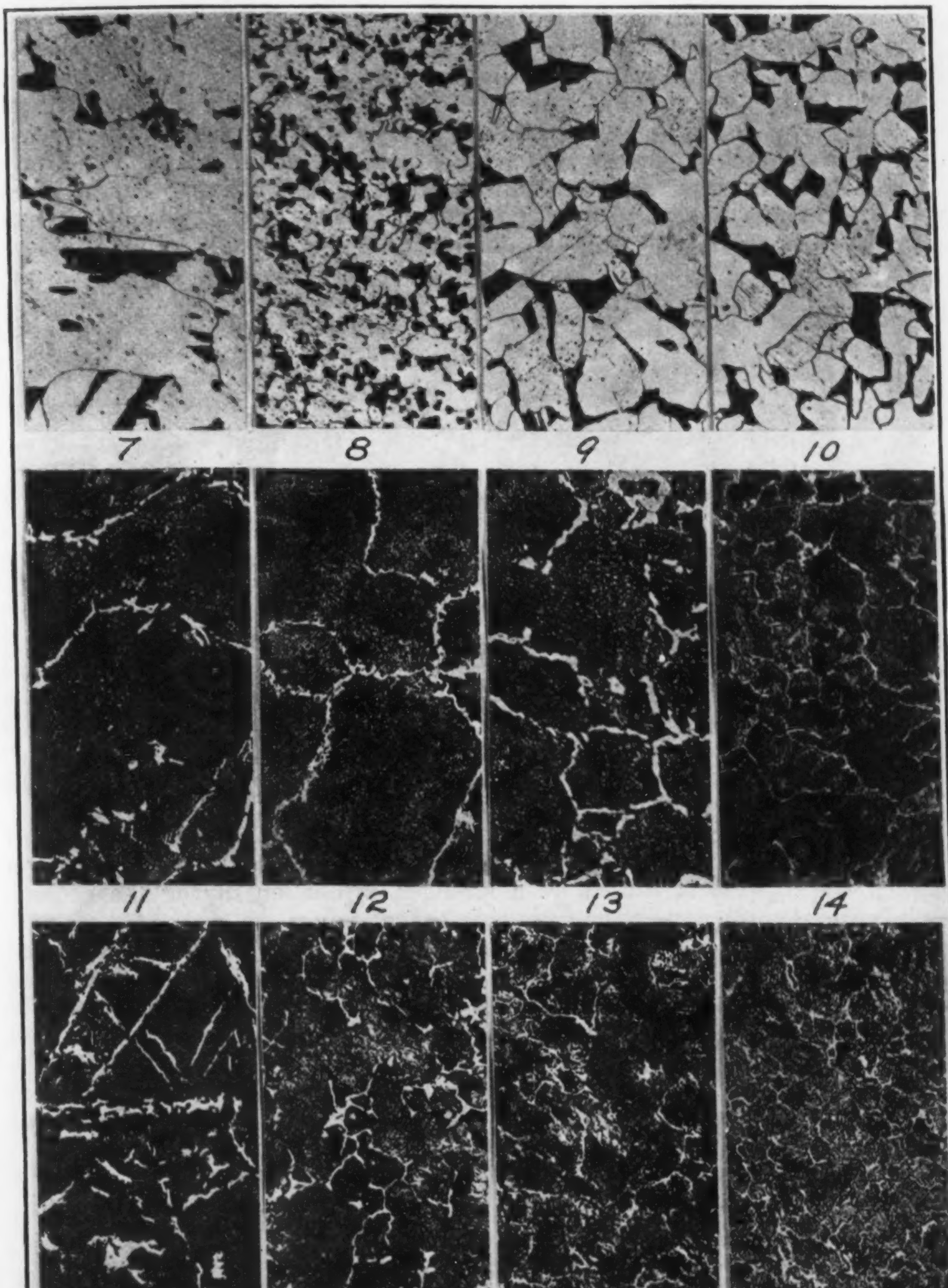


Fig. 7—Core of normal steel. X 100. Fig. 8—Core of abnormal steel. X 100. Fig. 9—Same steel as in Fig. 7 before carburizing. X 100. Fig. 10—Same steel as Fig. 8 before carburizing. X 100. Figs. 11, 12, 13, 14, 15 and 16 show steel having hypereutectoid zones of slightly abnormal type. X 200. Fig. 17—Hypereutectoid zone of abnormal type. X 200. Fig. 18—Hypereutectoid zone of abnormal type. X 200.

rather than giving these, he prefers to relate the experience in this respect that has been obtained under operating conditions.

Cones are usually packed inside the cups of the same bearing, but it is not unusual to receive a report from the carburizing department that this packing schedule has to be changed for certain lots, due to a slower penetration than normal in either the cups or cones. On investigation it is always found that the parts that were slow in carburizing were made of abnormal steel. Laboratory experiments verify this experience, and although it is hard to give exact figures, a maximum difference in depth of case of 15 to 20 per cent can be considered as a fairly good value. This statement is valid only for temperatures around or below 1675 to 1700 degrees Fahr., whereas at higher temperatures an abnormal steel will appear to carburize as fast as normal steel, but the writer is not ready to make any positive statements on this point, as his experience is based only on laboratory tests with a few specimens, and on a limited scale.

This feature in an abnormal steel giving a shallow case is combined with a tendency toward a higher maximum carbon content at the surface. On account of the pearlite divorce, it is usually impossible to determine microscopically with any accuracy the carbon content in the case of a steel of this kind, and an inexperienced observer is even likely to judge a very high-carbon case to be hypo-eutectoid or strongly decarburized. A normal steel gives no difficulty in this respect. It is thus necessary to resort to a chemical analysis, which of course, gives the only absolutely reliable figures. In one experiment, two test rings of identical shape, made of different steels, were packed close together in the same carburizing pot. The first cut of 0.010 inch showed a carbon content of 1.20 per cent in the abnormal, as compared with 1.07 per cent in the normal steel. This is a very undesirable feature, and makes, as will be shown later, the hardening of the abnormal steel still more precarious.

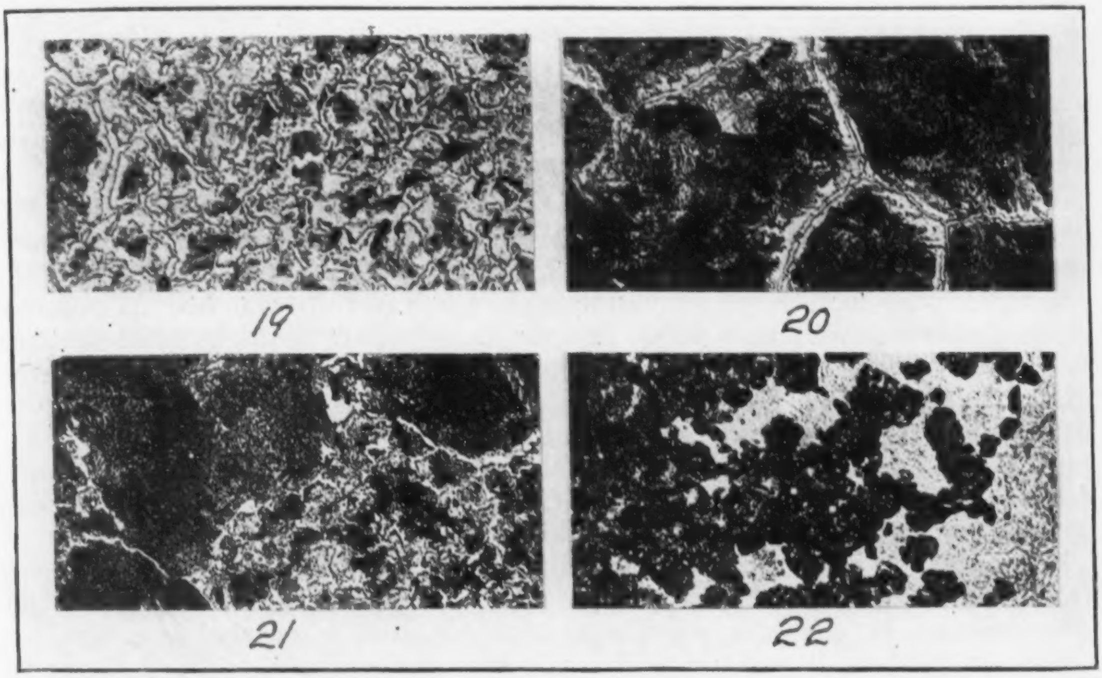
It is also noticed that the hyper-eutectoid zone of a strongly abnormal steel shows a more pronounced demarcation at the eutectoid zone than does a normal steel. This is caused by a stronger enfoliation during the cooling, as it is well known that at the carburizing temperature the carbon content decreases uniformly from a maximum at the surface to a minimum represented by the carbon content of the core. This enfoliation is presumably caused by the strong repelling action on the carbides from the impurities present in abnormal steel. A comparison is the formation of ghost-lines in steel, and this feature is also, by the way, a direct parallel to the fact that a nickel steel, which contains the nickel in solid solution in the ferrite, shows more enfoliation than a chromium steel where the alloying element is contained mainly as double carbides.

Hardening of Normal and Abnormal Steel

Briefly stated, normal steel will respond to heat treatment readily, and in the hardening operation will form martensite and become uniformly hard, while the abnormal steel will not respond readily, and in its worst varieties will not under any circumstances harden without soft spots. These soft spots are of irregular shape, size, and distribution. To a file they are more or less soft, and scleroscope readings run from 45 to 60, as against 75 to 90 for normal steel. Microscopical examination shows their structure to be more or less, and sometimes entirely, troostitic as shown in Fig. 22. On rehardening a carburized piece of this kind it is often found that the previously soft areas become hard, but also that, almost invariably, new soft spots de-

velop. In less extreme cases it also happens that the hardening is so far successful that the work appears hard to the file, but shows a soft surface after removing by grinding off a few thousands of an inch. That this phenomenon is not due to careless grinding, but to a hardness only surface deep, has been carefully checked.

Although somewhat more unusual, cases are found where the entire surface is soft. In one case, for instance, the carbon content was found by analysis to be 1.10 per cent in the outside layers, and in spite of extreme



Figs. 19 and 20 show steels having a hypereutectoid zone of abnormal type. X 200. Fig. 21—Hypereutectoid zone with mixed normal and abnormal structure. X 200. Fig. 22—Edge of soft spot showing troostite in hardened abnormal steel. X 200.

care in hardening under the writer's personal supervision the pieces were so soft that there was no difficulty in removing the entire case by filing. Failures in hardening of similar kinds of steels have from time to time been referred to the writer for investigation, by different manufacturers of case-hardened parts, and the failures have almost invariably been found to be due to more or less abnormal steel.

It is very often noticed that the surface of an abnormal steel after carburizing is spotted and unevenly colored, whereas the surface of a normal steel with the compound used gives a clean, uniformly grey surface. A similar difference is sometimes observed also after hardening.

The primary considerations in hardening of carburized work, as in all other hardening, are the hardening temperature and the accomplishment of a proper quench. The problem of hardening carburized normal steel is similar to that of hardening a well made tool steel. Several other precautions both as to temperature and quench must, however, be taken with abnormal steel, as the temperature must be raised and the quench made much more drastic than is necessary for normal steel. These points will be dealt with separately.

Influence of Hardening Temperature

A normal steel will, in the absence of excess cementite, give a properly refined case if hardened from 1420 to 1430 degrees Fahr. This applies to

work of small dimensions, but even for large sized work the temperature should never need to exceed 1450 to 1460 degrees Fahr., and if a higher hardening temperature is employed a coarse overheated fracture will be obtained. An abnormal steel behaves quite differently in this respect, and gives a fine-grained fracture even if the hardening heat be raised considerably above normal. It has even been found that in the case of the most abnormal steels, specimens quenched directly from the carburizing pots show fractures of the case resembling those of well-hardened, high-carbon chromium steel, whereas of course a normal steel quenched under the same conditions shows a very coarsely grained fracture.

Independent of the hardening temperature, very abnormal steel will harden with soft spots, but it has been found that with many of the intermediate types of steel an increase in temperature is beneficial. By using a hardening temperature up to 1525 degrees Fahr. a large amount of work can be salvaged, although this process is far from 100 per cent efficient. The proper hardening heat is determined by gradually raising the temperature, testing the hardness by file test, and breaking samples for examination of the fracture. This increase in temperature must be carefully watched, as different steels respond in different ways, and the cases where a fine-grained fracture is entirely independent of the hardening temperature are restricted to steels distinctly abnormal. Great care must also be taken, by periodical breaking of samples, that no work of normal steel is given this hardening at the higher temperature, which would result in a coarse-grained, entirely unsatisfactory fracture of inferior quality. In this respect the previously mentioned spotty appearance of some lots of abnormal steel is also a good indication. The soft spots are sometimes accompanied by a somewhat fiery coarse-grained fracture that cannot be refined by the employment of any hardening method. The fracture is somewhat similar to that obtained when the case, for one cause or another, is a little high in excess carbon, but is of a distinctly different nature and is undoubtedly due to some abnormality in the steel. The exact nature of this has, however, not yet been established, primarily because this fracture is comparatively scarce. The fracture has been observed in several types of abnormal steels, but is especially obtained when the steel in the carburized condition shows signs of pearlite divorce around isolated lines of cementite combined with a fairly large grain size.

In order to avoid any doubt as to the accuracy of the temperature given, it can be mentioned that they are all checked by recording instruments of potentiometer type in connection with platinum-rhodium couples, checked periodically against standard couples. The hardening furnaces are of the rotary hearth type with a central combustion chamber for oil or gas, and the temperature is controlled within $\pm$ 5 degrees Fahr. by automatic regulators of the company's own design.

It has been suggested that the reason for the failure in hardening abnormal steel would be that the cementite in the hyper-eutectoid zone once precipitated, could not again be readily brought into solution. This would not, however, explain why samples quenched directly from the carburizing pots show soft spots, and it has, moreover, through laboratory experiments with gradually increased hardening temperatures, been proved that the excess cementite is dissolved without difficulty. That the troostite formation is due to some other factor detrimental to the formation of martensite is above doubt and will be discussed later. Attention is, however, directed to the parallel of unstable pearlite in the carburized and unstable martensite

in the hardened steel, notwithstanding that in the hardening the troostite formation probably occurs directly from the austenite and does not pass the martensitic stage.

Influence of Proper Quench

In the hardening of common tool steel a faster quench than immersion in brine or flowing water is seldom necessary, and this is equally true of carburized work made from normal steel. The extreme types of abnormal steel cannot, however, be hardened under any conditions, and even intermediate types need a faster quench than that obtained by immersion of the work. This fact and the possibilities of much greater production have led to the adoption of a very powerful spray quench in specially designed hardening machines, working with water under a minimum pressure of 40 to 50 pounds per square inch and a maximum temperature of about 65 degrees Fahr. The use of this machine, facilitates the use of different quenching mixtures, resulting in a minimum warpage and uniform change in size. By this method all except the very worst types of steel can be satisfactorily hardened, especially if, in doubtful cases and for large work, the hardening temperature is raised as previously mentioned.

Influence of Maximum Carbon Content on the Case

It is, desirable to keep the carbon content as close to the eutectoid composition as possible, but this is especially for heavy cases, very difficult. When excess carbon is present in a normal steel the result will be freckled edge, but the hardness is not materially affected, even if the strength is lowered. The writer's experience with abnormal steels is that the difficulty in hardening, as regards soft spots, is greatly increased with the presence of excess carbon. This experience agrees well with the results by Portevin and Garvin[1] on the influence of the rate of cooling on hardening of carbon steels. Their investigation proved that a faster rate of cooling is necessary for the proper hardening of hyper and hypo-eutectoid steel than for eutectoid steel. This condition makes it still more difficult to harden an abnormal steel, which, as already mentioned, has a tendency to build up a higher carbon case than a normal steel, and it can be safely stated that even with steels of very abnormal types, the presence of excess carbon (1.05 per cent or more) is a necessary condition for the complete development of a soft surface in the hardening. As this condition is likely to be present in large sized work with heavy cases, most of the difficulty in hardening is experienced with work of this kind. A contributing factor to this is that the speed of quenching is slower for the larger than it is for the smaller work.

Based on this principle of keeping the carbon content as close to the eutectoid as possible, a method of salvage has been worked out that has been used with at least fair success in several instances where the work failed in hardening. The method consists simply in heating the work in a noncarburizing medium, such as saw-dust or coke breeze, for a sufficient time to allow for the diffusion of the excess carbon toward the core. In the subsequent hardening operation much better results are obtained, and although the method is far from fool-proof, several lots of especially large work ready for the scrap pile have been saved in this way. The application of the theories of Portevin and Garvin to the explanation of the failure in hardening will be dealt with later.

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1. Journal of the Iron & Steel Institute, 1919, No. 1, pp. 469-560.

Part II

Influence of Carburizing Temperature and Rate of Cooling On the Carburized Structure of Normal and Abnormal Steel

The structures described in Part I were obtained with a carburizing temperature of 1675 to 1700 degrees Fahr., followed by cooling in the pot. In order to develop a carburizing test that could be made on a laboratory scale and in the shortest time possible, experiments were run with higher carburizing temperatures and other changes that seemed likely to produce a rapid result. For the tests, specimens from two bars, one of normal and one of

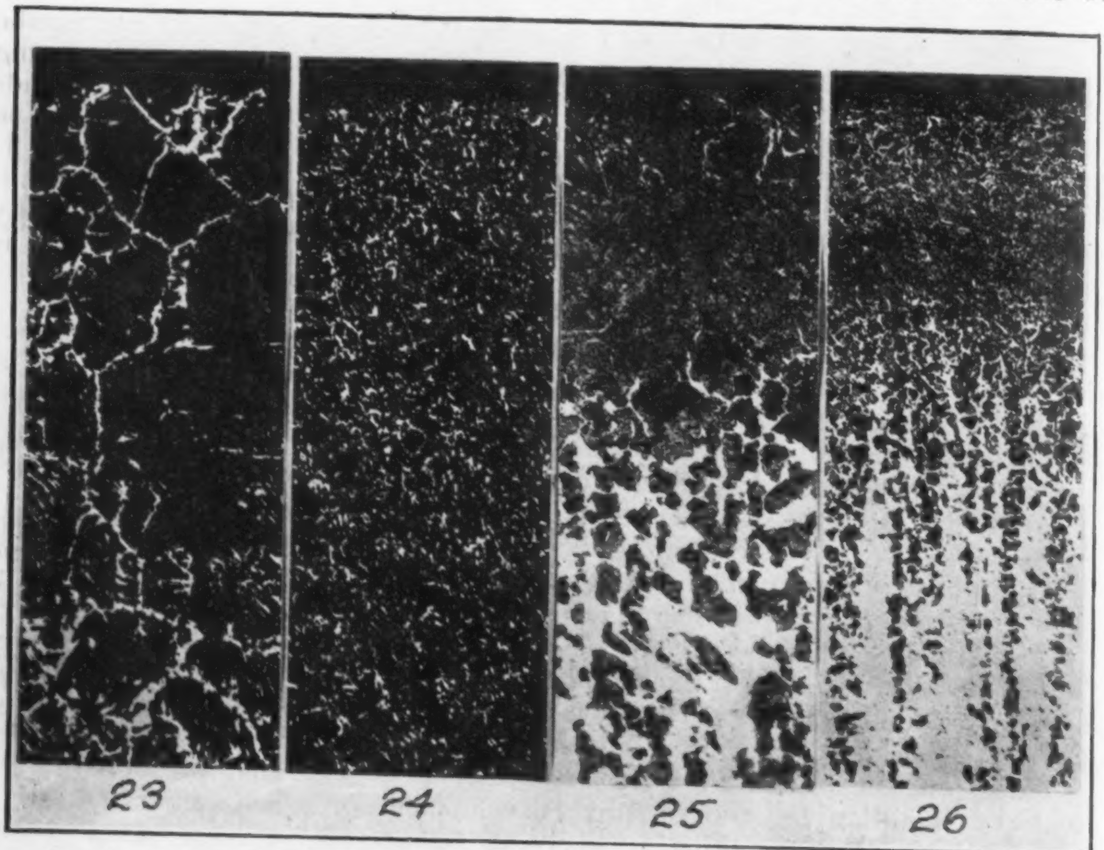

Fig. 23—Case of normal steel obtained with slow carburizing compound. X 50. Fig. 24—Case of abnormal steel obtained with slow carburizing compound. X 50. Fig. 25—Case of normal steel carburized for 8 hours at 1600 degrees Fahr. X 50. Fig. 26—Case of abnormal steel carburized for 8 hours at 1600 degrees Fahr. X 50.

abnormal steel, were packed with different compounds in small containers of 1½-inch x 6-inch steel pipes. The containers were heated in an electric furnace at 1600, 1700, 1800, 1900 and 2000 degrees Fahr. for varying lengths of time. One set of containers were also heated in a high-speed steel furnace at about 2250 degrees Fahr. The influence of the rate of cooling was studied by cooling at four different rates, as will be shown shortly.

Influence of Carburizing Compound and Time at Maximum Temperature

The variation in structure produced by different compounds is very slight. A fast carburizer will, however, give a test in a shorter time and the carbon content in the case will be higher, which, as already mentioned, is favorable to the development of the differences in structure, and compounds giving an eutectoid case are on this account not well suited for tests of this kind. Very

slow carburizers, for instance coke with a weak energizer such as glue, will give a hypo-eutectoid case, and the difference in structures obtained is similar to that in the gradation zone, but is much more pronounced and sometimes affords a very sensitive test as shown in Figs. 23 and 24. The influence of time is comparatively small, although a long heating accentuates the difference, due to the fact that a deep case always has a tendency for a higher carbon content at the surface. With a temperature of 1700 degrees Fahr. and an energetic compound a very distinct difference is obtained in two to three hours, but for actual tests, at least three to four hours should be allowed.

Influence of Carburizing Temperature

There are, as already mentioned, two distinct and different features characteristic of the structure in a carburized piece, namely the hyper-eutectoid zone, the gradation zone and the core. In an abnormal steel the structure in both these respects is changed with an increased temperature, but the change does not occur at the same temperatures. With the steel used for these tests the change in structure of the gradation zone and the core occurred at 1750 to 1800 degrees Fahr. whereas the change in the hyper-eutectoid zone occurred at about 1900 degrees Fahr. The structure in the normal steel at these temperatures remained practically unchanged (Figs. 25 to 34.)

The gradation zone and the core in an abnormal steel are, with low carburizing temperatures, fine-grained, with rounded pearlite areas. With an increased carburizing temperature this structure gradually disappears and a structure identical with that of a normal steel is obtained. With the two steels tested the dividing temperature range was 1750 to 1800 degrees Fahr. but this temperature is likely to vary with different steels, being higher for the very abnormal types. The structure of the hyper-eutectoid zone of an abnormal steel at a low carburizing heat is fine grained, with knotty or curly cementite and more or less disintegrated pearlite. In the tests made this structure gradually disappeared with an increase in the carburizing temperature, but persisted to a considerably higher point than the structure in the gradation zone and the core. The dividing temperature range was about 1900 degrees Fahr. and somewhat dependent on the carburizer employed, with a slightly higher temperature for a very energetic compound. Above this temperature both the normal and the abnormal steel showed a tendency to form a needle-like structure, although a slight difference was noticed up to about 2000 degrees Fahr. At still higher temperatures the structure was identical in both steels, consisting of solid pearlite with the cementite as very pronounced needles (Figs. 35 and 36.)

Influence of Rate of Cooling

The influence of the rate of cooling is considerably less than might be expected from previous investigations, and is quite overshadowed by the influence of the quality of the steel. The different rates of cooling and how they were obtained are shown in Table I. The table refers to the tests run at 1800 degrees Fahr. but the rates obtained at other temperatures were similar.

At the slowest rate of cooling there is a very pronounced enfoliation of the case and segregation both in the case and the core, as would be expected, but otherwise the structure is very similar to that obtained in the regular practice, and with the pipes cooled in kieselguehr or in the air, photomicrographs of which are shown in Figs. 37 and 38.

Specimens cooled freely in the air showed, on the other hand, a very

pronounced difference with the enfoliation and segregation almost entirely suppressed. At the edge, the excess cementite has not had time to segregate, but is precipitated uniformly through the pearlite, and the gradation zone and the core, especially at the higher temperatures, have a tendency to show the typical triangular structure of overheated steel as shown in photomicrographs Figs 39 and 40. At a slightly slower rate of cooling this structure is modified by coagulation phenomena, as previously shown.

Recommendations for Short Time Carburizing Tests

In order to obtain the greatest difference between different steels it is desirable that the structure be well developed both in the hyper-eutectoid and the gradation zones, although these requirements are to a certain degree contradictory. The most distinct difference in the hyper-eutectoid zone is obtained at about 1800 degrees Fahr. but at this temperature the transition zone will be coarse-grained, independently of the quality of the steel. In order to develop the typical fine-grained structure in this part and in the core of an abnormal steel it is thus necessary to use a lower temperature. The best results seem to be obtained at 1675 to 1700 degrees Fahr. and by using an energetic compound and small containers the tests can be made in a total time of three to four hours.

Table I
Method and Time Required in Cooling Specimens After Carburizing

Method of Cooling	Temperatures and Time Required to Cool Specimens: 1800 to 1700 degrees	1700 to 1800 degrees	1800 to 1500 degrees	1500 to 1400 degrees	1400 to 1300 degrees
1. Pipes cooled in furnace........	45 minutes	1 hour	1 hour 30 minutes	3 hours	6 hours
2. Pipes cooled in kieselguhr.....	5½ minutes	2½ minutes	2 minutes	2 minutes	2 minutes
3. Pipes cooled in air............	3 minutes	1½ minutes	1½ minutes	1½ minutes	1½ minutes
4. Specimens cooled in air........	1800 to 1300 degrees in about 2 minutes				

One method by which very fast and satisfactory results are obtained is by carburizing under pressure. The easiest way to effect this is by using closed containers, preferably made of some heat-resisting alloy, with tight-fitting covers and a carburizing meal that gives off plenty of gases during the time of heating. In carburizing as commercially conducted these gases are allowed to escape, but can be utilized to build up the desired pressure. In this way it is possible to obtain a distinctly hyper-eutectoid zone in a short time at a comparatively low temperature. Very sensitive results are also obtained by using a slow carburizing compound at a temperature of about 1700 degrees Fahr. In this way a maximum carbon content of .60 to .70 per cent is obtained, and the difference in structure is often very pronounced. For an all-round test the method with a fast carburizer, capable of producing a hyper-eutectoid case, is, however, to be preferred.

Part III

Explanation of Structures and Phenomena Encountered in Case-Hardening of Normal and Abnormal Steel

With the fact clearly established that the different structures and properties of carburized steel were due to some inherent property in the steel itself, present in the ingot and unchanged by later operations in the course of manufacture, it became necessary to establish the causes, and if possible duplicate these phenomena under laboratory conditions. The writer believes that both of these problems have been successfully accomplished and the conclusion arrived at is, that they are caused by the presence in the steel of

minute ultra-microscopical solid particles of non-metallic impurities, presumably oxides, due to improper deoxidation of steel when made. For details in regard to proof for this contention, the earlier papers (See Page 1 of original manuscript) and following discussions are referred to. The following summary of the different points in favor of this theory will be sufficient:

1. *Behavior and structure of ghostlines in carburized work.* (*Fig.* 41)
2. *Influence of artificially produced inclusions and of fragments of mill scale in carburized work.* (Figs. 42 *and* 43)
3. *Structures produced in welding, followed by carburizing.* (*Fig.* 44)
4. *Carburizing qualities of burnt steel and steel exposed to oxygen in the molten condition.* (*Figs.* 45 *and* 46)
5. *Carburizing qualities of steel as connected with furnace practice and different stages of electric furnace heats.* (*Figs.* 47 *to* 50)
6. *Influence of different deoxidizing reagents.*[2] (*Figs.* 51 *and* 52)

It is freely admitted that the evidence is somewhat circumstantial and that it has been subjected to some rather severe criticism, but it is also true that in addition to several of the leading American metallurgists, who have accepted the proof as conclusive, the well-known French scientist, Professor Portevin, who is especially entitled to speak with authority on this subject, in a contribution to the discussion of the paper presented at the Iron & Steel Institute, endorses the writer's theories and mentions that he has independently been led to similar conclusions.

Just how this influence from the oxides in the steel is exerted in order to produce the properties described as normal and abnormal, has been a matter of much speculation. That the oxides are evenly distributed through the steel is beyond doubt, but whether in solid solution, in colloidal solid solution, or suspended as minute particles in the steel, is very difficult to decide. There is, for one thing, no difference in the heating and cooling curves of the different steels, and the fact that the rate of diffusion of the impurities is very slow, as shown by the perseverance of unmixed normal and abnormal portions of steel in the same specimen, even after prolonged heating, gives certain support to one of the two latter theories. The fact, on the other hand, that in steel surrounding inclusions of mill scale, an actual solution and diffusion of the oxides take place, affords certain support to the theory that the oxides are actually in solid solution in the steel and that an equalization does not take place in steel with mixed structures should, according to this view be due to the solution pressure being so much lower than that of the concentrated bodies of oxides in the latter case. The writer personally is most inclined toward a theory of colloidal solid solution, but for a satisfactory theoretical explanation of the phenomena encountered in carburizing and hardening these considerations can be laid aside although they are of great theoretical interest.

If a theoretical explanation of this nature is accepted, it becomes quite evident that the oxygen content determined, for instance, by the Ledebur method, will not in any way be an indication of the properties of the steel. An analysis of the oxygen content will mainly give the oxygen content of the occluded gases, which have no influence on the structure and will probably not include the

2. Experiment by Dr. Boylston, Carnegie Scholarships Memoirs, 1916, Vol. VII, Experiment II.

oxygen content of the oxides, as a reduction of the oxide particles will be very difficult to obtain. If the oxide particles consist of SiO_2 or Al_2O_3, such a reduction will manifestedly not take place, and in at least a few experimental cases, evidence has been obtained that Al_2O_3 actually was the active body in causing abnormal properties.

Explanation of Structures Obtained in Carburizing Before Hardening

Recalling the differences between normal and abnormal steel, the following features should be explained:

	Normal Steel	Abnormal Steel
Depth of case and maximum carbon content.	Deeper, with less maximum carbon content than abnormal steel.	Thinner, with higher maximum carbon content than normal steel.
Core	Large grain size. Angular outline of pearlitic areas. (Fig. 7.)	Small grain size. Rounded outline of pearlitic areas. (Fig. 8.)
Gradation zone	Same. (Fig. 5.)	Same. (Fig. 6.)
Hypereutectoid zone...	Large grain size. Cementite at grain boundaries in network. Large solid areas of pearlite. (Fig. 3.)	Small grain size. Cementite as curly fragments surrounded in extreme cases by ferrite formed by the more or less complete disintegration of the pearlite. (Fig. 4.)

The combination of a shallow case and a higher carbon content in abnormal steel can be explained in the following way. In the carburizing pot the carboniferous gases, chiefly CO, will at the carburizing temperature penetrate into the steel and deposit part of their carbon content. Just how deep this penetration of the gases is, is somewhat doubtful, but it is well known that the higher the pressure of the gases, the deeper will be the case and the deeper will presumably be the penetration of the gases into the steel, or at least the deeper will the penetration of active gases be, before they have been deprived of their surplus carbon by the surrounding iron. At the low pressure that is used in commercial carburizing practice, it is reasonable to assume that most of the carbon is deposited close to the surface and that this amount of carbon is practically independent of whether the steel is normal or abnormal. The transportation of carbon toward the core in a piece being carburized can, however, be visualized as taking place not only by means of the carboniferous gases, but also by the migration of the carbon, and on this diffusion toward the core of the carbon, impurities are likely to have a strongly repelling influence. This will, if as presumed, approximately an equal amount of carbon is deposited close to the surface of the steel, result in a thin case with higher carbon content for the abnormal steel.

The variation in grain size that is noticeable both in the case and the core is a question of extreme interest, as it opens up the question of control of crystallization and grain size in iron obtained not only in carburizing but also in all other kinds of heat treatment operations. The writer has observed a large variation in grain size not only in plain carbon steels, to which this article mainly refers, but also in a large number of different steels containing such alloying elements in varying proportions, as chromium, nickel and vanadium. The analysis of the steel has undoubtedly some influence, but is by no means the predominant one and the writer is inclined to believe that the grain size in the steel in general after heating at temperatures around and below the Ac_3 point, are largely governed by the presence in the steel of non-metallic impurities. Their effect is exaggerated by a carburizing operation, but are readily obtained also after prolonged heating at the proper temperature without a carburizing compound.

The different properties of normal and abnormal steel were, as already men-

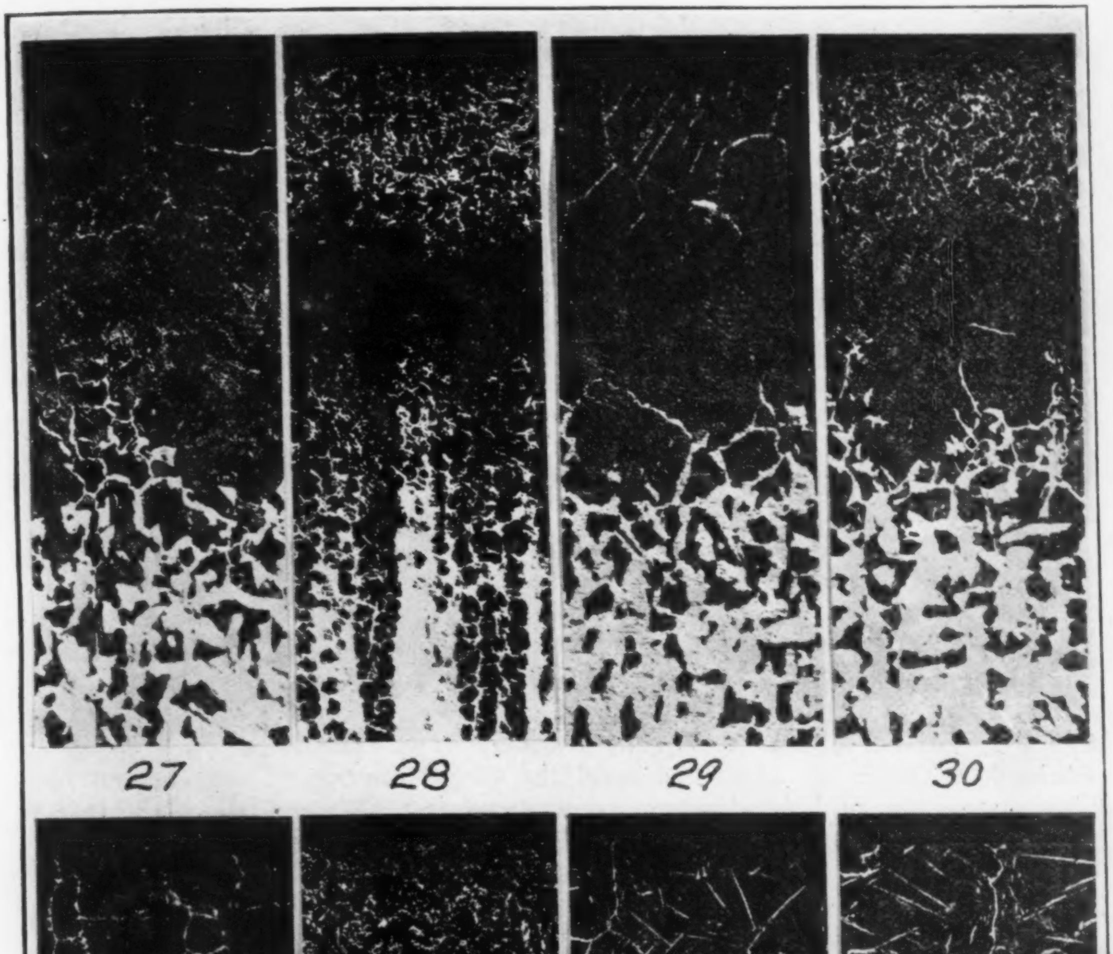

Fig. 27—Case of normal steel obtained in 8 hours at 1700 degrees Fahr. X 50. Fig. 28—Case of abnormal steel obtained in 8 hours at 1700 degrees Fahr. X 50. Fig. 29—Case of normal steel obtained in 8 hours at 1800 degrees Fahr. X 50. Fig. 30—Case of abnormal steel obtained in 8 hours at 1800 degrees Fahr. X 50. Fig. 31—Case of normal steel obtained in 2 hours at 1900 degrees Fahr. X 50. Fig. 32—Case of abnormal steel obtained in 2 hours at 1900 degrees Fahr. X 50. Fig. 33—Case of normal steel obtained in 2 hours at 2000 degrees Fahr. X 50. Fig. 34—Case of abnormal steel obtained in 2 hours at 2000 degrees Fahr. X 50.

tioned, in an early stage of this investigation, traced back to the ingot and the different characteristics in regard to grain size have presumably originated during the solidification of the steel in the ingot. Professor E. D. Campbell of the University of Michigan who was consulted on this subject wrote in reply to a question by the writer as follows:

"In regard to the diminution in grain size, where impurities are present, I think it is not improbable that this is due to the increase in the number of centers of crystallization, as it is well known in ordinary solutions that to obtain large crystals the number of centers of crystallization should be reduced to a minimum. As you probably know, if crystallization in a solution can be started at one point only a single crystal will often grow to a remarkably large size, whereas agitation of the solution or the addition of dust or other small particles of solid materials which serve as centers of crystallization, will bring about the formation of a very large number of small crystals or grains. In normal steel the grain size will depend upon the composition, initial temperature, and the rate of cooling, and it is at least thinkable that a local increase in the concentration of impurities might, by increasing the number of crystallizations, produce a very marked change in grain size."

According to this theory, the starting points for crystallization in a "clean" and well-deoxidized steel are much fewer than in the abnormal steel, where a large number of oxide particles serve as starting points for the crystals. In the normal steel comparatively few well-developed crystals are obtained, while in an abnormal steel the large number of crystals interfere with the growth and development of each other. This explains the cause of both the larger grain size with the angular or triangular outlines of the pearlite in a normal steel (Fig. 5) and the smaller and more rounded areas of pearlite in an abnormal steel (Fig. 6). This point of view is supported by the experience of Dr. Giollitti[3], from whom the following quotation is taken:

"Solidification must start somewhere, and it is known that the first nuclei appear at determined points in the cooling melt. As I have already mentioned, the formation of the first germs of crystallization is one of the most important phenomena among the many occurring during solidification. The properties characteristic of the solid alloy depend to a very large degree upon the number of centers of crystallization and the cause of their formation. So strongly, in fact, does this state of affairs impress itself upon the metal, that the vestiges remain even after all the heat treatment and mechanical work to which it will be afterwards subjected."

That the way the solidification takes place is of primary importance for the future properties of the steel is thus above doubt, and by assuming that the oxides are distributed as minute particles in the steel, presumably in a colloidal solution, and that they retain their mutual positions in the steel, and later, under favorable conditions arrange the crystals in accordance with this outline, an explanation would be obtained how the influence from the solidification is carried through the different stages of conversion and heat treatment of the steel. It is, however, no material deviation from this theory if the variation in grain size is considered as being caused directly by the presence of impurities in the steel, and this point of view might seem preferable, if a more direct explanation is desired. Messrs. Jeffries and Archer[4] have in a series of articles entitled "Grain Growth and Recrystallization in Metals"

3. Giollitti, "Heat Treatment of Soft and Medium Steels," translated into English by Thum and Vernaci, pp. 13 and 14.

4. Chemical & Metallurgical Engineering, Feb. 22, March 1 and March 8, 1922.

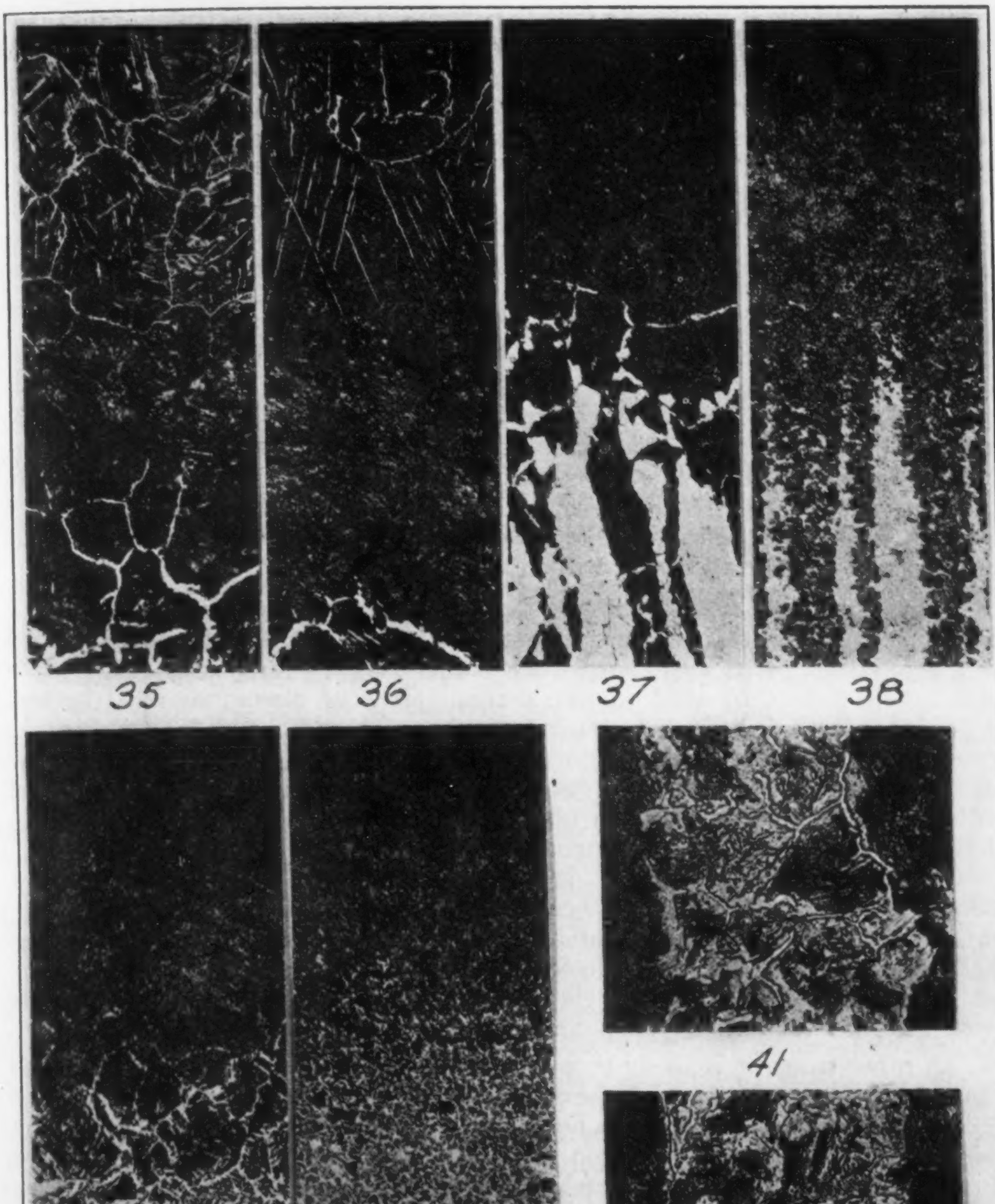

Fig. 35—Case of normal steel obtained in 2 hours at 2200 degrees Fahr. X 50. Fig. 36—Case of abnormal steel obtained in 2 hours at 2200 degrees Fahr. X 50. Fig. 37—Case of normal steel carburized at 1600 degrees Fahr. for 8 hours cooled very slowly. X 50. Fig. 38—Case of abnormal steel carburized at 1600 degrees Fahr. for 8 hours, cooled very slowly. X 50. Fig. 39—Normal steel carburized at 1600 degrees Fahr. for 8 hours, cooled in air. X 50. Fig. 40—Abnormal steel carburized at 1600 degrees Fahr. for 8 hours, cooled in air. X 50. Fig. 41—Ghost-lines in hypereutectoid zone of normal steel. X 200. Fig. 42—Artificial inclusion of manganese sulphide in the hypereutectoid zone of normal steel. X 200.

made an exhaustive study of the factors governing recrystallization and grain size in metals, and in their articles it is shown how the presence in a metal of finely divided impurities will under favorable conditions, cause a fine grain size. Their experiments were made with thoria and tungsten, but there are many indications that similar laws govern the grain size in steel, with non-metallic impurities as the obstructing material against grain growth.

Just of what kind and of what concentration these impurities must be to influence the grain size in steel is very difficult to ascertain, but there is reason to believe that any kind of finely divided impurities in solid solution will produce this effect. This has been shown by introducing various chemical compounds into drilled holes in bars of normal steel, that have afterwards been forged down, annealed and carburized and it has been found that a large number of bodies, usually considered as insoluble in steel, in reality are soluble to a slight extent at high temperatures, and that they invariably will produce abnormal structure and a fine grain size. That the impurities in the commercial steels dealt with in this paper, consist of oxides, or some chemical compound containing oxygen is, however, fairly certain, but it is evident that it is very difficult to determine the exact nature of these compounds, as this problem can only be approached in an indirect way.

In one or two instances it has, however, been possible to draw some direct conclusions on this point, and notably in the case when aluminum is used as a deoxidizer. It is customary when taking samples for analysis during the pouring of a heat of steel to put a small piece of aluminum into the test mold in order to produce test pieces without blow holes. A steel rich in gases to which an aluminum addition has been made, will invariably show abnormal properties with a fine grain size after carburizing, whereas the steel without the aluminum additions although containing blow holes will usually show a perfectly normal structure with a large grain size after carburizing. In this particular instance Al_2O_3 is undoubtedy the active element in causing the fine grain size. This experience is mentioned without intention of passing judgment on the value of aluminum as a deoxidizer, but it can be pointed out that if aluminum is used as a deoxidizer, sufficient time must be allowed for the Al_2O_3 to coagulate and be removed from the bath, at least if the steel is to be used for carburizing purposes.

In other cases, it is likely that the impurities consist of FeO in combination with SiO_2 or MnO, and there are certain reasons to believe that pure FeO is comparatively scarce, as FeO would be reduced by the carboniferous gases in the carburizing operation. If such a reaction took place a change in structure would be affected equal to the penetration of the carburizing gases, and such a change has been noticed only in a very few cases. The writer is at present trying to assemble added evidence on this point and experiments have been outlined to more accurately determine the factors that govern the grain size of steel in carburizing. It is hoped that these experiments later can be broadened so as to comprise the question in general of grain size in steel around and below the Ac_3 point.

The condition mentioned in Part II that the fine grain size in abnormal steel disappears with the employment of temperatures considerably above the Ac_3 point is explained by the fact that the natural tendency of grain growth from a high temperature overcomes the obstructing influence of the impurities against grain growth and the greater perseverance of the fine grain in the hyper-eutectoid zone as compared with the gradation zone and the core can

be explained by the presence of more impurities in this part in the form of excess cementite.

Relative to the structure of the hyper-eutectoid zone in carburized work, the divorce of pearlite in abnormal steel is well explained by the presence in the steel, of oxides in solid colloidal solution. The powerful repulsive influence of oxides on iron carbide is very clearly shown by the formation of ghost-lines in steel, as already mentioned in a previous part. In the case of an abnormal steel the excess cementite is precipitated with a gradually decreased temperature, and with cementite particles as nuclei the pressure from the oxides, presumably in solution in the ferrite, is strong enough to cause a partial disintegration of the pearlite, the degree of which is dependent on the amount of oxides present in the steel. Professor Campbell, when asked his opinion on this matter, gave the following answer:

"In normal steel above the critical point the carbides form a homogeneous, probably colloidal solution, which persists until the critical point is reached, when, as the gamma iron goes over to the alpha state, in which the carbides are but slightly soluble, the precipitated carbides assume the form of thin plates, characteristic of normal pearlite. It is well known that the addition of a comparatively small amount of electrolyte to any colloidal solution in water will bring about coagulation or flocculation of the colloid, and I think it not improbable that the disolved oxides in your abnormal steels function in a manner exactly analogous to that of electrolytes in aqueous solutions, thus bringing about the flocculation or coalescence of the carbides, either before transformation takes place or during the critical period.

This question of divorce and varying stability of pearlite in carburized work is closely related with the properties of pearlite in other kinds of steel, and the experience in this respect related in this paper does not agree very well with the results obtained by previous investigators. Howe and Levy[5] investigated the influence of rate of cooling and maximum temperature on the stability of pearlite, whereas an investigation by Honda and Saito[6] shows that the divorce of pearlite is influenced by carbon content and maximum temperature. The observations by these authors that a higher temperature gives a more stable pearlite, and that an excess carbon content facilitates a divorce, agrees in a general way with the writer's experience, but he has also found that the influence of the quality of the steel is at least of equal, if not of greater importance than these factors. The direct comparison between carburized pieces and the steels of uniform carbon content, employed in these previous investigations, is open to some criticism, due to influence of segregation and enfoliation phenomena in the carburized piece during the cooling, even if the writer's experience is that they do not materially affect the results obtained. In order to offset this objection, thin strips of normal and abnormal steel have been carburized through, and afterwards soaked at about 1600 degrees Fahr. for a sufficient length of time to equalize the carbon content, thus producing samples of eutectoid and hyper-eutectoid composition, that can be regarded as similar to the steel used for the earlier tests. These samples retain all the characteristics of the original steels, and there is as marked a difference in the stability of the pearlite in these specimens as in the hyper-eutectoid zone of carburized work.

It can be said that the data given in the above-mentioned papers agree with the results obtained with normal steel, but decidedly not when abnormal

5. Journal of the Iron and Steel Institute, 1916, No. II.
6. Journal of the Iron and Steel Institute, 1920, No. II.

steel is concerned. There is no reason to believe that the properties described as abnormal in this paper should be restricted to low-carbon steels, and experience in hardening spring steels, which will be dealt with shortly, gives an actual example of a high-carbon steel with abnormal properties. This is also a very important question in the annealing of high-carbon steels, which principally consists in a spheroidizing of the cementite in the pearlite. This operation is mainly governed by the way the pearlite responds to the annealing temperature and subsequent cooling, and that in this procedure the results are dependent not only on the temperature and the rate of cooling, but also on the quantity of impurities present, is quite evident. The impurities react in the same way as excess cementite and facilitate the spheroidizing of the pearlite, but they are also, on the other hand, detrimental to the proper hardening of the steel, as will be shown in the next paragraph.

Explanation of Phenomena Encountered in Hardening of Normal and Abnormal Steel

The main problem to be explained is the difficulty in hardening abnormal steel, and particularly the occurrence of some troostitic spots in the worst types of steel. The fine-grained fracture in hardened work can be explained by the same reasons mentioned for the fine-grain size in carburized work, namely, a residual influence from the solidification of the steel in the ingot, or if so is preferred, a direct obstructing influence against grain growth from the impurities in the steel. This also explains the fact that the fine-grained fracture of a hardened abnormal steel is, with previously mentioned limitations, independent of the hardening temperature employed.

In explaining the occurrence of troostitic spots, the previously mentioned article by Portevin and Garvin[7] on the influence of the rate of cooling on hardening of carbon steel gives important information. Other conditions being equal, it is a well-known fact that the formation of troostite in hardening is dependent on the rate of cooling, and these authors determined by carefully recorded cooling curves and microscopical examination, just what minimum speed of quench will give a martensitic hardening. The rate of cooling was recorded at the center of the hollow cylinder, and the speed was varied by using cylinders of different diameter, applying a spray quench of water to the outside. The results showed that the formation of troostite corresponds with a sudden evolution of heat about 1200 degrees Fahr. called by the authors Ar′, but that with a greater speed of quench, in, for example, smaller cylinders, this evolution is depressed and occurs gradually at about 600 degrees Fahr., called Ar″, giving as a result a martensitic structure. These results show that troostite, when obtained in hardening, is formed directly from the austenite and does not pass the martensitic stage, as is often assumed. This troostite former in hardening is of a rounded and bulky appearance, such as shown in Fig. 22, which represents the structure of a soft spot in hardened abnormal steel, and is of a distinctly different nature to the troostite obtained by drawing back a hardened martensitic steel, where the troostite follows the outline of the needle structure of the martensite.

Curves No. 1 and No. 2 in Fig. 53 represent graphically and somewhat exaggeratedly from the curves given in the original paper the quench at different speeds of samples made of the same steel, No. 1 corresponding to a troostitic and No. 2 to a martensitic quench. There is, in other words, for every steel a fixed and certain minimum speed of quench that will produce a

7. Journal of the Iron and Steel Institute, 1919, No. I.

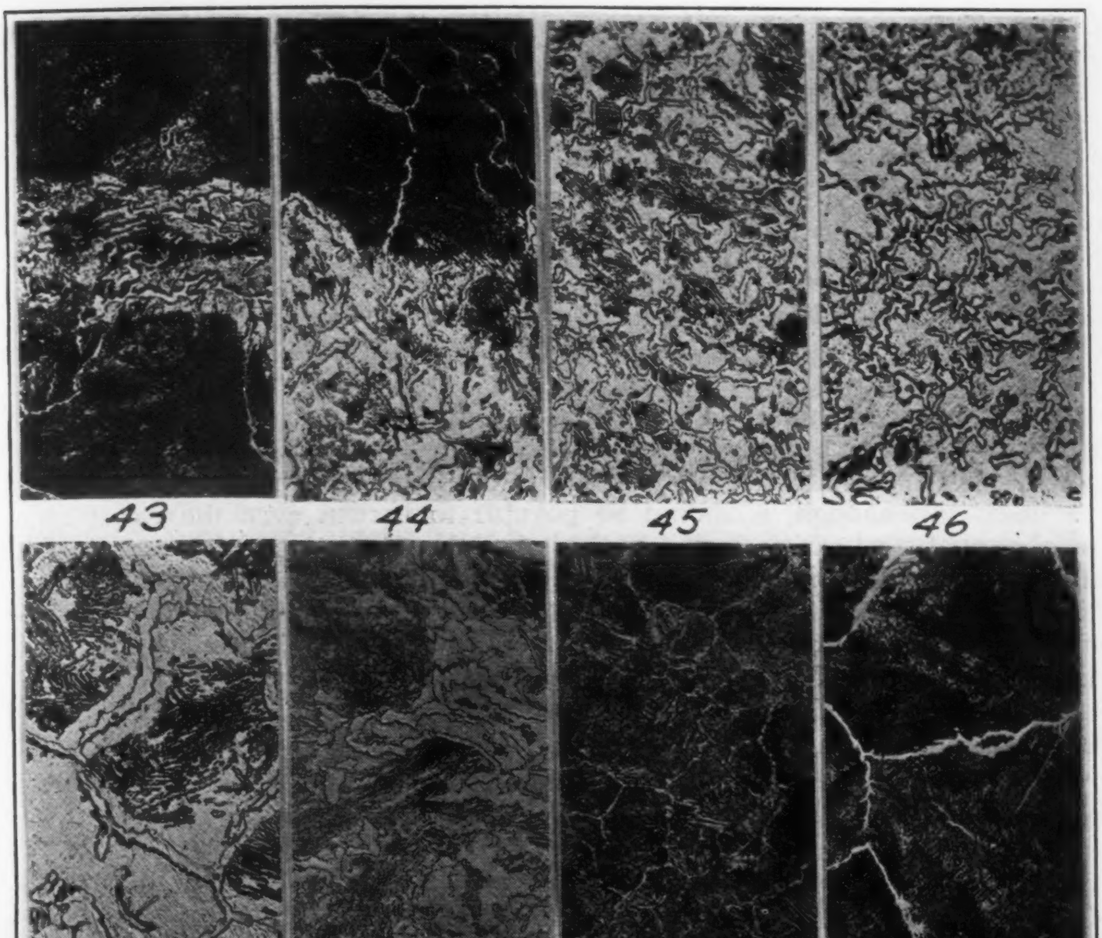

Fig. 43—Crack with mill scale close to surface—carburized. Fig. 44—Hyper. zone carb. oxy-acetylene weld. Fig. 45—Hyper. zone badly burnt steel. Fig. 46—Hyper. zone steel blown with oxygen. Fig. 47—Hyper. zone steel immediately after melting down. Fig. 48—Same steel after 1st additions. Fig. 49—Same steel immediately before tapping. Fig. 50—Same steel in finished condition. X 50. Fig. 51—Hyper. zone steel deoxidized with Fe Mn. Fig. 52—Hyper. zone steel deoxidized with carbon free Fe Ti. Fig. 53—Carb. spring steel which gave good results in H. T. Fig. 54—Carb. spring steel, erratic in H. T. All Figs. X 200.

martensitic structure, and if the quench be slower than this, more or less troostite will be obtained. Reverting to the hardening of normal and abnormal steel with the strong spray quench previously described, it can be safely assumed that with work of the same size, the same speed of quench is obtained. This means that an imaginary cooling curve of the surface of a normal steel would have the appearance of curve 3, Fig. 53, with no anomaly in the curve at 1200 degrees Fahr. (Ar′), but with a gradual heat evolution below 600 degrees Fahr. (Ar″) representing the formation of martensite, and that in an abnormal steel the cooling presumably proceeds like curve No. 4 with a heat evolution of 1200 degrees Fahr. (Ar′), corresponding with the formation of troostite, and then with approximately the same rate as curve No. 3, to 600 degrees Fahr., and from this point down, faster. In the normal steel the speed obtained by immersions is already sufficiently fast to suppress the Ar′ point, but with more or less abnormal steel this speed approaches very closely to or exceeds the critical rate. There is no doubt that if the quench could be made fast enough, it should be possible to harden even the worst types of abnormal steel satisfactorily, but this is, at least commercially, not possible, although for many intermediate types of steel that are close to the boundary line the employment of the strong spray quench brings them over on the safe side. The experiments on surface hardness in hardening by Prof. Benedicks and Dr. McCance have apparently been made with samples of normal steel, well on the safe side, and thus comparatively independent of the speed of quench.

In explaining the beneficial influence of a raised hardening heat, the experience of Portevin and Garvin was that with a higher initial temperature an indication of suppressing the Ar′ point is obtained, which fact the authors ascribe to a modification in the nature of the transformation phenomena. Apart from this, other factors that can be better controlled by an increased temperature also enter into a commercial hardening operation. When a piece of steel is quenched under commercial conditions the cooling of the surface is likely to proceed after a curve such as No. 3 Fig. 53 with a slight incline at the start of the curve, representing the cooling of the piece in the transfer from the furnace to the quenching machine and in the machine, before the quench has acquired full strength, due to steam pockets and similar reasons. It is mainly the speed with which the steel passes through the Ar′ range around 1200 degrees Fahr. that determines whether troostite formation is obtained or not, and the influence of this incline is, with normal hardening temperature, likely to reach into this critical range, and if the steel is abnormal a troostitic quench will be obtained (Curve No. 4, Fig. 53). By raising the hardening temperature this incline at the start of the cooling curve No. 5, Fig. 53 occurs at a higher temperature, and the passing of the Ar′ range is accomplished at such a high rate that formation of troostite does not occur. This applies to steel of intermediate types, whereas for steel of the most abnormal kind this suppression of the troostite formation is not possible, even with the high speed of cooling obtained in this way (Curve 6, Fig. 53).

That the different properties of the normal and abnormal steel, in regard to their hardening, are connected with the presence of oxides in the steels is beyond doubt, and there is no great difficulty in explaining how this action is exerted. The experimental results by Portevin and Garvin showed that a hyper-eutectoid steel needs a faster rate of cooling, in order to give martensite, than does a steel of eutectoid composition, the reason for this fact being that the particles of excess cementite in the hyper-eutectoid steel act as nuclei

for the formation of troostite. The action of the oxides can be explained in an identical way, and the more impurities present in the steel, the more numerous are these starting points for the troostite formation, and the faster the rate of quenching required for a proper hardening. The action, in this respect, of the oxides or any other kind of impurities can be visualized as being of very much the same nature as that of solid particles introduced into super-saturated salt solution, and a good example is afforded in the old experiment of making a super-cooled solution of Glaubers salt suddenly freeze by introducing foreign solid bodies into the liquid.

This behaviour of abnormal steel in hardening is one of the reasons why the writer is more inclined towards the theory that the solution

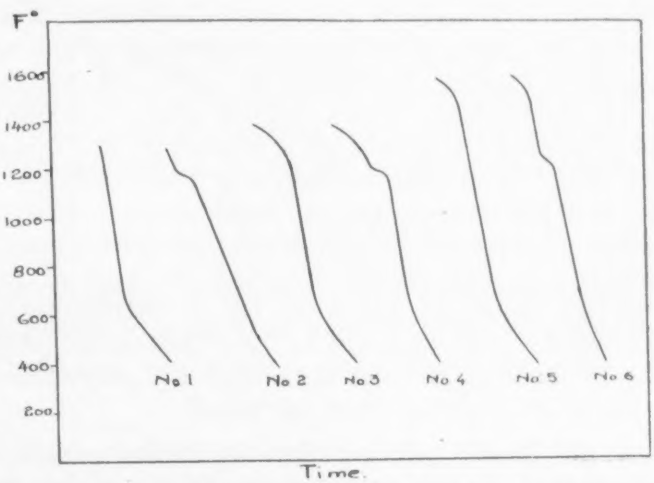

Fig. 55—Represents graphically the different quenching speeds of samples made of the same steel. For every steel there is a fixed and certain minimum speed of quench which will produce a martensitic structure. If the quench be slower than this minimum more or less troostite will be obtained.

of the oxides is of colloidal nature, with minute particles of oxide throughout the steel, just as the solution of carbide in gamma-iron probably is a colloidal solution. Such a hypothesis gives a very satisfactory explanation to properties of an abnormal steel and the different phenomena encountered in its heat treatment.

Conclusions

The results obtained in commercial carburizing are, as shown in this paper, very much dependent on the quality of the steel, and as these qualities cannot be determined by the usual chemical or physical test methods, the practical value of a carburizing test is obvious. A better product with uniform hardness, less operating trouble, and fewer rejections due to improper hardening, would be the ultimate result.

It is necessary for tests of this kind that microscopical examinations of carburized sections be made; but these do not, if properly conducted, involve a large amount of work, and after a little experience it becomes a very easy matter to determine from the carburized structure whether the steel is suitable for carburizing or not. Carburizing on a laboratory scale can be carried out in a few hours, especially if some kind of tight-fitting containers are employed in accordance with the recommendations made in Part II. It must be understood, however, that a test of one specimen from, for instance, a large heat of open-hearth steel is not a perfect safeguard against improper steel, as different

parts of a heat often show different carburizing qualities. Even one sample from each heat is, however, likely to catch the worst cases, and if several samples from each heat are tested, a reasonable security against improper steel should be obtained. Tests of this kind constitute moreover, a distinct warning to the steel mills not to send their off-heats to consumers who are known to submit the steel to tests of this kind.

For most carburizing purposes, a clean, well made, straight low-carbon steel (S.A.E. 1020) would be satisfactory, especially if hardened by spray quench to counteract small variations in the steel. Owing to the difficulty of obtaining a steel of this kind of uniform and proper quality in the open market, the author is inclined, however, to recommend for general carburizing purposes a steel with 0.30 to 0.50 per cent chromium. For parts subjected to a very severe service, steels with higher content of alloys such as chromium, nickel, and vanadium, can be recommended, although for ordinary purposes are out of the question owing to the higher price. A slight percentage of chromium, such as suggested, would give a steel of good carburizing properties; as it is very unusual to find a chromium steel with abnormal properties, would not raise the price very much, would rather help than impair the machining qualities, as straight S.A.E. 1020 steel often tears under the tools on account of being too soft, would increase the rate of penetration in the carburizing somewhat, would be beneficial for the hardening, and, last but not least, would necessitate carefully deoxidized heats, as otherwise so much chromium would be lost in the furnace that the chromium content in the finished steel is likely to be lower than specified.

The writer would finally call attention to the important fact that this influence of oxides in steel is not restricted to carburized low-carbon steel only. They will, if present, materially influence the results obtained in heat treating and hardening of any steel. In the preceding, the probable influence on grain size and structure of work submitted to tough annealing operations, and on the spheroidizing of the cementite in annealing high-carbon steels have been mentioned. It is an interesting fact that by carburizing high-carbon steels so as to obtain a carbon content of 1.10 per cent or over, a very sensitive test on the degree of deoxidation is obtained, and that in several instances it has been possible to prove by this method that failures in hardening were due to the presence of oxides in the steel. A well-deoxidized, high-carbon steel should give the structure described as normal in this paper, while abnormal properties are revealed mainly by irregular grain size. Figs. 51 and 52 show, for instance, the edge of two carburized pieces of spring steel, the first of which was reported to have given excellent results in heat treating, while the results with the latter were erratic and irrgular. The two steels were of approximately the same analysis, with the same physical properties, and with no difference in the microstructure before carburizing. Several similar instances could be given, with the results agreeing closely with the record of service for the different steels.

In conclusion, the writer wishes to express his sincere gratitude for the interest, help, and advice extended him by Mr. M. T. Lothrop of the Timken Roller Bearing Company and Mr. H. W. McQuaid of The National Pressed Gear Co. He is also grateful to Prof. E. D. Campbell of the University of Michigan, Ann Arbor, for valuable advice, and to Prof. H. M. Boylston of The Case School of Applied Science, Cleveland, for important steel samples.

HEAT TREATING IN LEAD

By R. B. Schenck

Abstract of Paper

The lead pot furnace has, in recent years, been applied to volume production in steel treating with considerable success. While molten lead is far from being an ideal heating medium, it is the only metal which can be successfully employed for this purpose; and in comparison with the salts in commercial use as bath materials, it has the advantage of a much wider range of working temperature and a much higher heat conductivity. These two properties permit the use of lead in units of very large capacity for temperatures of 650 to 1700 degrees Fahr., thus covering the hardening and tempering ranges of nearly all commercial steels.

The selection of pot materials, the design of the pots and brickwork, and the method of firing are points of prime importance and must receive considerable attention if efficient operation is to be obtained. The unit should be built for the job it is intended to handle, bearing in mind at the same time the desirability of standardization.

While some parts cannot be treated efficiently in lead, there are many which can be handled very successfully. Axle shafts, transmission gears and many smaller parts are now being hardened from lead pots, and a greater number are being tempered in lead. The lead furnace has its greatest range of usefulness for tempering operations, and many parts can be tempered in lead which cannot be efficiently quenched from this type of furnace.

Comparing the lead pot with the oven furnace from the standpoint of operation cost, a great deal depends on the nature of the work handled, but in general, it can be stated that for hardening, the oven furnace is the cheaper of the two, and for tempering, the costs are slightly in favor of the lead pot.

Taking everything into consideration, the greatest argument for the lead pot furnace is the high quality of the treated product resulting from uniform and accurate temperatures. It is very difficult, if not impossible, with an oven furnace to obtain the degree of uniformity which exists throughout a lead pot. Experience covering a period of years has proven, at least to the author's satisfaction, that where conditions permit of its use, the lead pot can produce consistently better work than any other form of heating unit.

A paper to be presented before the Detroit Convention Oct. 2-7. The author, R. B. Schenck, is metallurgical engineer, Buick Motor Co., Flint, Michigan.

THE use of molten lead as a heating medium dates back many years. In the old days the lead pot was a relatively unimportant unit in the hardening room, being used principally for special work where local hardening or tempering was desired. Today, however, this type of furnace has assumed a more prominent place in the industry, and has been applied to volume production with considerable success.

The ideal liquid heating medium would have certain definite physical and chemical properties. It would be low in price, non-poisonous, free from moisture and any tendency to absorb it, high in heat conductivity, low in electrical conductivity, high in specific heat, low in specific gravity, would not adhere to the work, and would have a total working temperature range of 300 to 2400 degrees Fahr., throughout which it would be stable in composition and chemically inert with respect to the atmposphere, the work to be treated, the various alloys used for pots and the commercial refractories.

There are logical reasons for each of these properties. The desirability of low price and non-poisonous qualities is self-evident. Permanent freedom from moisture is highly desirable for reasons with which we are all familiar. High heat conductivity insures more uniform temperature throughout the bath, resulting in better quality of work, larger production, and longer life of the pots. Low electrical conductivity permits electrical heating by internal resistance, which is advantageous for very high temperatures. High specific heat prevents large temperature drops when cold steel is introduced, thus maintaining better thermal stability. Low specific gravity permits the work to sink in the bath, thus making it unnecessary to use special fixtures to insure complete immersion. The specific gravity is also an important consideration in connection with cost, as all such materials are purchased by weight and used by volume. A tendency to adhere to the work causes mechanical loss of the bath material, and in some cases considerable expense due to the necessity of cleaning. A total working range of 300 to 2400 degrees Fahr. would permit the use of this ideal bath material for the treatment of all steels, including high speed steel. Changes in composition, or breaking down under heat, which takes place in some compounds, forming a sludge in the bottom of the pot, greatly interferes with efficient operation. Oxidation by the air either aids in this breaking down, or forms dross with its attendant evils. Chemical attack on the work and on the pot results in injury to the former due to decarbonization and scale, and decreases the life of the latter. Chemical action on the commercial refractories causes destruction of the brick work in the combustion chamber when leaks occur in the pots.

Commercial Bath Materials

The various bath materials in commercial use fall into two classes: metals and salts. Of all the metals, lead is the only one which offers itself for serious consideration. It is relatively low in price, non-poisonous if properly handled, permanently free from moisture, high in heat conductivity, high in electrical conductivity, low in specific heat, very high in specific gravity, does not adhere to the work unless impure or oxidized on the surface, has a total working temperature range of 650 degrees to 1700 degrees Fahr., is oxidized readily by the air at all temperatures when molten, and while the metal itself has little chemical action on the work and pots, its oxide, which always forms to some extent, does attack them, especially at high temperatures. It has a strong slagging action on the acid refractories, and causes rapid deterioration of the brick-work if much of it gets into the combustion chamber.

While it is not the intention in this paper to cover in detail all of the

various liquid heating madiums in use, a brief discussion of the more important ones and their properties in comparison with lead, may be of interest. The principal salts in commercial use as bath materials are the cyanide, chloride, carbonate, and nitrate of sodium. The cyanide, chloride, and nitrate of potassium were also formerly employed for this purpose, but on account of their higher cost have been largely replaced by the sodium salts. Sodium hydroxide, barium chloride and calcium chloride are of less importance, although they are in use to some extent. In some cases the bath is composed of a single salt, but generally two or more are mixed in certain proportions depending on the properties desired.

The salts and salt mixtures in most common use fall into three classes: the high cyanide mixtures, the low cyanide mixtures, and sodium nitrate. The first two are used in the hardening range and the third in the tempering range. For convenience we will classify as high cyanide mixtures those containing 40 per cent or more sodium cyanide, and as low cyanide mixtures those with less than 40 per cent of the cyanide salt. In the first classification we have the commercial products known as "96-98 per cent Sodium Cyanide," "73-76 per cent Cyanide chloride," and a number of mixtures containing sodium chloride and sodium carbonate as well as sodium cyanide. These mixtures, especially the one known as "73-76 per cent Cyanide-chloride," are largely used for cyanide case-hardening, although some of them are employed merely as heating mediums, the case-hardening effect not being especially desired. Those coming under the second classification are used almost entirely as simple heating mediums. They are made in a great number of different compositions, and almost always contain both sodium chloride and sodium carbonate in addition to the sodium cyanide, which sometimes runs as low as 1 per cent. The third class, which is of less importance, comprises sodium nitrate. Although this salt seems to be about the best for low temperature work, its heat conductivity is so low that its use is limited to small units operated at low output.

Practically all the commercial salt bath materials are cheaper than lead in first cost per unit of volume. Their ultimate cost compared with lead is an entirely different matter, and depends on a number of factors. All of the salt mixtures containing cyanide are extremely poisonous and must be handled accordingly. They will all pick up moisture, and should be shipped and stored in air-tight containers. Their heat conductivity is much lower than that of lead, sodium nitrate being by far the worst in this respect. They are low in electrical conductivity, high in specific heat and low in specific gravity. Steel sinks readily in all of them. They all adhere to the work, which results in large mechanical losses, but due to their solubility in water the work is easily cleaned. None of them have the flexibility of lead in temperature range. The cyanide mixtures have a working range of about 1300 to 1700 degrees Fahr., varying with their composition, and sodium nitrate a range of about 700 to 1100 degrees Fahr. The cyanide mixtures continually lose cyanogen and if the content of NaCN is too low will form a sluggish bath accompanied by a sludge in the bottom of the pot. It may be that both of these actions are due, in part at least, to oxidation by the air. The cyanide mixtures, with the exception of their carburizing action, do not attack steel or iron, unless they are too low in cyanide, in which case they have a tendency to decarbonize the work and corrode the pots. They have a detrimental effect on pots made of the nickel-chromium alloys regardless of the cyanide content. All the commercial salt bath materials tend to slag the acid refractories, although they are not as bad as lead in this respect.

Lead

The two outstanding properties of lead, which make it greatly superior to the salts as a heating medium for large production, are its very high heat conductivity and its wide working range of temperature. The salts have their field of usefulness, but they are necessarily limited to small units operated at a comparatively low output.

In purchasing lead for use as a bath material the ordinary grade of pig lead known as "Prime Western" seems to be as good as any, although some of the metal companies have special grades for this purpose which they claim will give better results. Cases have arisen where trouble caused by lead sticking to the work has been traced to a small content of tin, the lead used having been refined from dross, and the tin accidentally introduced in the refining operation. In most cases, however, when a complaint comes from the hardening room that the lead is no good and they cannot keep the work clean, a little investigation will show that the pots have not been properly covered or the covering itself is at fault.

Pot Materials

Lead pots are generally made of cast iron, cast steel or one of the special heat-resisting alloys. Cast iron is used mostly below 1300 degrees Fahr., while steel and the special alloys are employed for the higher temperatures. Ordinary cast iron, does not, as a rule, stand up well above 1300 degrees Fahr., although with very slow firing, it has been known to give good service at 1400 degrees Fahr. The special alloys are generally composed of nickel, chromium, and iron, and some of them are very high in price. The most expensive alloys cost ten or twelve times as much as cast steel per pound, and it is usually necessary that these high priced pots have a life of several thousand hours in order to compete with steel pots. The determining factor is the ultimate cost of the whole heating unit per ton of treated work, which takes into consideration such items as fuel consumption, maintenance of the brick work and shut downs.

Pot and Furnace Design

The design of the pot is of prime importance. The corners should be properly rounded, and the thickness of the sides and bottoms worked out for the best economy. There is considerable difference of opinion throughout the industry in the matter of pot design, some favoring very thick bottoms with thin or tapering side walls, and others thin bottoms with side walls of the same thickness. The material of which the pot is made is an important consideration in connection with design, the nickel-chromium alloys, in most cases, requiring lighter sections. As in the case of selecting the proper material, the design must be figured out on the basis of ultimate cost. A pot with very thick walls and bottom may last much longer than a lighter pot, but when all the various factors are taken into consideration, the lighter one may prove to be the more economical of the two.

Second in importance to the design of the pot is that of the brickwork. Direct flame impingement on the pot is, of course, fatal, and every effort should be made to avoid it. The so-called "return flame" method of firing shallow rectangular pots with a single burner, in which the flame travels from one end of the combustion chamber to the other and back again, gives excellent results. In this type of furnace the pot hangs by the flange, the bottom of the pot forming the top of the combustion chamber, which is divided longitudinally into two parts by a brick wall having an opening at the end opposite the burner. The long flame obtained in this way gives very uniform heating

and high thermal efficiency. This construction can be used for either gas or oil fuel, but is especially advantageous when using oil, which has more of a tendency to cause localized heating. In all except the smallest units the outer walls consist of 9 inches of fire-brick without any special insulation. Insulating brick would do very little good as the heat losses through the walls are negligible compared with those from the surface of the lead. The height of the combustion chamber when firing with oil should not be less than 10 inches. The burner should be fastened rigidly in the proper position so that it cannot be pointed upward toward the pot. With some oil burners a splash brick is not necessary, but the usual type requires one, and for this purpose an ordinary standard fire brick placed with the $2\frac{1}{2} \times 4\frac{1}{2}$ inch face toward the burner answers every requirement.

With the above furnace the brick work is very simple in construction, cheap and easily repaired. A shallow rectangular pot of any size can be fired in this way, and it is needless to point out the advantages of the single burner as compared with two or more. Attempts have been made to protect the pot by building a brick arch between the pot and the combustion chamber, but this construction tends to reduce the rate of heating, lowers the thermal efficiency, and stores up a large amount of heat which interferes with temperature control. An added objection is the rapidity with which the arch burns out necessitating frequent repairs. It is probable that any increase in the life of the pot resulting from this arrangement could be obtained without the arch construction by simply reducing the rate of heating to the same point as with the arch.

Deep pots, such as are used for hardening camshafts, are generally round, although some square ones are in use. The round ones are set in either a round or square brick work, and are usually tangentially fired by two or more burners placed at different levels. If square in section they are set in a square brick work and fired in a similar manner. Deep pots are not often hung from the flange, the general practice being to stand the pot on a pier in the bottom of the combustion chamber. Pots of considerable depth are expensive to install, as they have to be set in a pit in order to have the top at the correct working height, or the operators have to work on an elevated platform. Due to the small surface of lead exposed to the air, and the large side wall area, insulating brick can be advantageously used in this type of furnace, which is not the case with the shallow pot furnaces as explained above.

Protective Coverings

Lead, on account of its tendency to oxidize at all temperatures when molten, the rapidity of oxidation increasing with the temperature, must be covered with some protecting medium. Without a suitable covering, the lead loss is excessive, and the work comes out covered with oxide and metallic lead which are often very difficult and expensive to remove. Wood charcoal, corncob charcoal, charred nut shells, charred leather, coal coke and petroleum coke are some of the materials in commercial use as pot coverings. Hard wood charcoal, size No. 3, such as is used in the manufacture of carbonizing compound, is one of the best, but is not always the most economical. A great deal depends on the nature of the work and the temperature of operation in determining the most suitable covering. In hardening transmission gears the best covering obtainable is, as a rule, none too good, while in hardening axle shafts coal coke or the cheapest grade of charcoal screenings will answer the purpose, providing the tempering treatment is also performed in lead.

The action of the carbonaceous coverings is both chemical and mechanical, their efficiency depending to a great extent on the rapidity with which they burn, and the temperature at which burning starts, sometimes called the kindling teperature. The chemical action is due to the reducing effect of CO gas which is generated by the combustion of the covering. Below the kindling temperature no CO is generated and the protective effect becomes entirely mechanical. Coal coke has such a high kindling temperature that it is practically useless in the tempering range, although it makes a good covering for some classes of work in the hardening range. Wood charcoal has a much lower kindling temperature, somewhere in the neighborhood of 850 degrees Fahr. Although the tendency of lead to oxidize increases with the temperature, it will give a great deal more trouble at 800 degrees Fahr. than at 950 degrees Fahr., when wood charcoal is used.

An interesting example of this occurred in tempering axle shafts. These shafts had been treated at 950 degrees Fahr. in a large lead pot using a wood charcoal covering, and practically no trouble was experienced from lead sticking to the work. Due to a change in the steel the temperature was lowered to 800 degrees Fahr., and trouble started at once. The shafts were so dirty that it cost in the neighborhood of fifty dollars a day to clean them, and although other coverings were tried and the lead skimmed more frequently, the results were just as bad or worse. The trouble was finally overcome by dipping the shafts in molten caustic soda immediately following their removal from the lead, and then quenching them in water. The result was perfectly clean work and a considerable saving in lead, several tons being recovered from the caustic soda pot each month. This process has been in use for some time and has saved a great deal of trouble and expense. The caustic soda pot is held at a temperature of about 775 degrees Fahr. which maintains good fluidity, and is low enough to prevent the chemical action which this salt exerts on the pots at higher temperatures.

The size of the covering has a great deal to do with its effectiveness. The most efficient size seems to be that of No. 3 charcoal, and this applies to all the various materials. Large lump charcoal is no good at all, and if purchased in this form it has to be crushed. Dust is unpleasant to handle and packs so closely that the generation of CO is slowed down at the lower temperatures.

Depending on the nature of the work, the kind of covering employed, and the temperature of operation, the bath must be skimmed more or less frequently. The coverings burn to an ash which settles on the surface of the lead and interferes with the action of the CO gas. Moreover, the protective effect is never perfect and a certain amount of oxide will always form, even under the best conditions. This ash and oxide must be removed and replaced with new material every so often or trouble will result.

Molten salts have been tried as coverings but with rather indifferent results. Caustic soda will work well at the start when used at low temperatures, but there is a gradual accumulation of lead oxide which soon causes trouble. Sodium nitrate is still worse due to its strong oxidizing effect. Mixtures of sodium and calcium chlorides have been used as coverings at temperatures as high as 1650 degrees Fahr., but they tend to break down and form a sludge, and although the work comes out perfectly clean, they are very expensive due to the large quantity consumed. Another objection is the necessity of melting these mixtures in a separate pot and adding them in the molten condition to the lead. They also tend to decarbonize the work, which, in some cases, is very troublesome. Of all the salts, the cyanide

mixtures are the best for high temperature work, but they are so expensive compared with the solid coverings, that their use is rather limited. The protective action of salt coverings is entirely mechanical except in the case of those containing cyanide. As long as no oxidation takes place very little lead adheres to the work, and if the work is water quenched the explosive effect when the adhering salt strikes the water removes the last traces of lead. A very decided objection to the use of salt coverings on large pots is the great amount of heat radiated from the surface of the bath, which results in bad working conditions for the operators, and undoubtedly lowers the thermal efficiency of the unit. The solid coverings have a marked blanketing effect which is almost entirely absent with the salts.

Methods of Operation

Lead pot furnaces can be operated by either the batch or continuous methods. For tempering, the former is by far the most satisfactory, while for hardening, both methods are successfully employed. In using the batch method, the pot is filled to its full capacity and the work completely removed as soon as the desired temperature is reached. It is generally necessary to shut off the burner before removing the work, but in some cases, if charging and drawing are sufficiently rapid, the burner can be allowed to remain open. With the continuous method, the bath is held at the desired temperature, part of the load being removed and replaced with cold work at certain intervals.

In hardening axle shafts, continuous operation has given very satisfactory results. A large oil fired installation operated in this way consists of a twin furnace, the two pots being placed side by side and fired independently of each other. The twin construction lowers the installation cost, saves floor space, and reduces the heat losses. The shafts are handled from the end of pot, suitable fixtures being provided to hold them under the lead. The return flame method of firing is employed, the burner being placed at the end opposite the operator. The pot which is made of nickel-chromium alloy, is rectangular in form, and has a lead capacity of 3600 pounds. The temperature control consists of recorder, deviation meter, and signal lights, set for an operating range of 1500 to 1530 degrees Fahr. A timing device controls a light which flashes every 1½ minutes, this being the signal for the operator to quench a certain number of hot shafts and replace them with cold ones. The hot shafts are removed from the side of the pot next to the quenching tank, those remaining in the bath moved over, and the cold ones placed in the opposite side, thus insuring a certain definite time of heating. For shafts up to 1⅜ inches in diameter, 4½ minutes of heating is sufficient. With this furnace it is possible to handle 1500 pounds of steel per hour in each pot.

A similar insatllation for hardening transmission gears is operated by the batch method. In this case the pot, which is the same as those used for axle shafts, is installed as a single unit, and the work is handled from the side, the gears being held on hooks and suitable fixtures. After a cold charge of gears is placed in the bath, the burner is turned on full, and then shut off when a certain temperature is reached, the bath being allowed to "drift" to the required temperature. The output of this unit is about 1000 pounds per hour. The batch method is employed in this case because of the effect of longer heating in preventing distortion of the work.

The installation previously mentioned for tempering axle shafts, consists of a rectangular pot of 8000 pounds lead capacity capable of handling better

than 3000 pounds of steel per hour. This unit is fired with a return flame, and is operated by the batch method. The pyrometer equipment includes a recorder, deviation meter, and signal lights. A load consisting of 200 axle shafts is charged and the burner turned wide open. At 750 degrees Fahr. the burner is closed and the temperature allowed to "drift" the rest of the way. The desired temperature is 800 degrees Fahr., and it has been found by experience that this unit has a 50 degree "drift." As soon as equilibrium is reached the shafts are removed and dipped in a caustic soda pot, and then water quenched to remove the adhering lead. The work is not removed from the pot until the temperature has become stationary, thus insuring uniformity throughout the whole bath. A number of these units are also in use for tempering propeller shafts, crankshafts, front axles, steering knuckles, connecting rods and numerous other parts. During the war crank shafts for the Liberty Motor were handled in a furnace of this type.

Thermal Efficiency

The thermal efficiency of a lead pot furnace increases very rapidly with the output, and for this reason it is highly desirable to operate as near as possible to maximum capacity. In this paper the efficiency will be expressed in pounds of steel heated to the desired temperature per gallon of oil consumed. A test on a unit of 3000 pounds lead capacity working on axle shafts at a temperature of 1500 to 1520 degrees Fahr., and fired with a return flame, gave an efficiency of 136 pounds per gallon at an output of 1200 pounds per hour. The same pot fired without the return flame gave an efficiency of 98 pounds per gallon at the same output. Further tests without the return flame showed efficiencies of 88 and 128 pounds per gallon at outputs of 1022 and 1532 pounds per hour respectively. These figures illustrate the increase of efficiency with output and the superiority of the return flame method of firing.

A further test was made on the same unit in which the pot was fired by the return flame method, and the air for combustion was preheated by the waste gases. The preheating was accomplished by passing the air through a steel pipe surrounded by the products of combustion in a long flue. With the air preheated to 700 degrees Fahr. and an output of 1094 pounds per hour, the thermal efficiency was 175 pounds per gallon.

Very high efficiencies can be obtained by preheating the work in an auxiliary pot heated by the waste gases. A test was made on an equipment of this sort, in which the two pots were built into the same brickwork and placed side by side, the flame traveling the length of the high heat pot, through an opening in the dividing wall, and back under the preheat pot to the vent. The pots were of the same dimensions as those in the tests just described. The high heat pot was run at 1500 to 1520 degrees Fahr., the preheat pot adjusting itself to a temperature of 1000 to 1100 degrees Fahr. The work, which consisted of axle shafts, was handled by the continuous method, several shafts being quenched at stated intervals and replaced by the same number from the preheat bath, these in turn being replaced by cold ones. With outputs of 968 and 1607 pounds per hour, respective efficiencies of 182 and 248 pounds per gallon were obtained. In operating this unit without the preheating pot, an output of 1086 pounds per hour gave an efficiency of 104 pounds per gallon. To bring the high heat bath up to 1500 degrees Fahr. on Monday morning, after standling idle over the week-end, required 10.04 gallons of oil, and to hold it at this temperature whe no work was being put through, required 1.69 gallons of oil per hour. The above installation, while capable of extremely high thermal efficiency, was not economical from the

standpoint of labor cost, as the shafts had to be handled twice, thus requiring two operators instead of one. The increased labor cost was much greater than the saving obtained through lower oil consumption.

Lead Consumption

The amount of lead consumed in lead pot furnaces varies greatly, and is dependent on the temperature of operation, the frequency with which the pots fail, the size of the unit, the nature and quantity of the work handled, the kind of covering used, and the care exercised in keeping the bath clean and properly covered. In general, the lead consumption should not run over .5 pounds per 100 pounds of steel heated. This figure tends to increase at the higher temperatures on account of the greater ease with which the lead oxidizes, but because of the increased chemical activity of the covering, the difference is less than might be supposed. Also, at temperatures below the point at which the generation of CO commences in the covering, the consumption of lead is generally very high. The figure given above does not, however, represent a total loss, since the dross and skimmings have a marketable value.

The consumption of the carbonaceous coverings varies somewhat depending on a number of factors. An extensive test on a pot handling axle shafts at 1500 degrees Fahr., and using a charcoal covering, showed a consumption of 1.23 pounds of charcoal per square foot of bath surface per hour. Under the same conditions with a coke dust covering the consumption was .96 pounds. A large tempering pot handling axle shafts and other parts at temperatures of 950 to 1050 degrees Fahr. showed a charcoal consumption of 1.16 pounds.

A test on a pot using a salt covering consisting of half and half sodium and calcium chlorides, and operating on axle shafts at 1500 degrees Fahr., showed a salt consumption of about 3 pounds per square foot of bath surface per hour. Expressing this in terms of weight of shafts handled, the consumption was about 2 pounds of the salt per 100 pounds of steel. The latter figure is preferable in this case, as the salt loss is entirely mechanical and depends on the amount carried away by the steel.

Cost Considerations

In considering the question of cost, there seems to be a prevalent opinion throughout the industry that lead pot furnaces are very much more expensive to operate than those of the oven type. While this is true in many cases, there are some jobs which can be handled in lead at an appreciable saving. The lead pot generally gives its greatest economy when used for tempering operations on parts such as axle shafts, which can be easily handled in bulk. For such work, the labor cost can be reduced to a figure comparable with that obtained in any other type of furnace. Large tempering pots, such as those previously described, can be installed for less than 20 per cent of the cost of an equivalent capacity in oven furnaces. Moreover, the lead furnace occupies but a fraction of the floor space required for the same oven furnace capacity. Installation cost and floor space occupied are important items, as they are represented by definite overhead charges. Large tempering pots also have the advantage of lower fuel consumption. A general comparison from the cost standpoint shows the lead pot furnace, when used for tempering, to be more economical in fuel consumption, first cost, occupied floor space, and the necessary overhead charges for the last two items; while the oven furnace has in its favor the item of low maintenance, taking into consideration the consumption of pots, lead, and coverings for the lead unit.

For hardening work, the operating cost of the lead pot does not compare so favorably with that of the oven furnace. The former occupies a smaller amount of floor space, and the first cost is usually less, but the maintenance cost is much higher. The lead pot can be operated at higher fuel efficiency by preheating the air for combustion, but ordinarily the fuel cost is about the same in both furnaces. The labor cost varies greatly with different jobs, but is generally higher with the lead furnace.

In spite of the usual higher cost of the lead hardening operation itself, it is sometimes possible to effect a saving by this method through the elimination of pickling or rattling, and by treating after the machine work is done. Axle shafts which are too hard for commercial machining after heat treatment, and which must be held accurately to size, can be treated in lead after machining with excellent results. Large quantities of shafts are being handled in this way at what is believed to be a lower total cost than by any other method.

Conclusion

Taking everything into consideration, the greatest argument for the lead pot furnace is the high quality of the treated product resulting from uniform and accurate temperatures. It is very difficult, if not impossible, with an oven furnace to obtain the degree of uniformity which exists throughout a lead pot. Experience covering a period of years has proven, at least to the author's satisfaction, that where conditions permit its use, the lead pot can produce consistently better work than any other form of heating unit.

(*Continued from page* 1110)

quantity of steel involved justifies the expense, it is possible to select the most suitable structure with great exactness. When there are a number of different machining operations to be performed upon the same steel, it is usually necessary to adopt a compromise structure which is fairly well suited to all the operations. It will usually be found that this structure which best satisfies the requirements of all the different operations will be one of ferrite, spheroidized cementite and pearlite in which only a small percentage of lamellar pearlite remains, as shown in Fig. 13.

(*Continued from Page* 1176)

all of them appeared to be brittle, though fine-grained. At low magnification, ghost lines were prominent (Fig. 28), and at 1000 diameters (oil immersion) the structure proved to be a sorbo-troostite (Fig. 29.) The carbon, manganese, and chromium content exceeded the specification by 0.02, 0.16, and 0.20 per cent, respectively. It was concluded that the high combined content of hardening elements made a steel unsatisfactory for the severe torsional stresses in heavy duty springs. A higher drawing temperature to counteract to some degree the excess of hardening elements would have produced a more satisfactory structure.

STANDARDIZATION OF METHODS LEADING TO COMPARATIVE PHYSICAL PROPERTIES OF ALLOY STEELS

By R. M. Bird

TODAY, as never before, designers, material engineers, consumers and producers are concerned with the relative values of alloy steels. The decision as to the type of steel to select for a given part is often not easy to reach. The man, upon whom rests the responsibility of making the decision, has to consider many things; primarily, the ultimate service of the finished part, frequently its forgeability and machinability; availability of stock, and always its cost.

For heat treated parts he is concerned with the physical properties which can be regularly secured; not, after fussy laboratory heat treatments, but obtainable, within reasonable limits, in a modern heat treatment shop. For alloy steels this latter consideration, balanced against cost, is usually the deciding factor.

Dependable information on this subject heretofore has not been generally available, and many incorrect selections, due to insufficient or inaccurate data, have led to disastrous results. What we all want, and particularly we of the American Society for Steel Treating, is authentic and comparable data of this kind especially for small bars up to 1½ inches in diameter, with information as to how to change our treatments for large and irregular sections, and how much less to expect of the physical tests from these large sections as compared with the small bar considered as a base.

The work of the Steel Standards Division of the Society of Automotive Engineers has, in the writer's opinion, been the biggest factor in standardizing alloy steels; and their respective physical property charts and recommended heat treatment practices (which, after their intensive work over the last two years, will soon be available) will be of considerable help to everybody. Later, upon these charts as a base, will undoubtedly be built more information as to what to expect from larger sections.

At the Bethlehem Plant of the Bethlehem Steel company, we have been accumulating data of this sort for many years. Shortly after the Armistice, in an effort to reduce to a minimum all controllable variables affecting final results, and to reduce our comparisons to a common small bar base, we put into routine operation a system which yields more consistent and, therefore, more truly comparable results than any previously familiar to us. Perhaps a description of our procedure may be of general interest.

First, let me emphasize the fact that we guard against, at all times, so called "laboratory results." The aim is to secure final figures which are a guide to results produceable under good commercial heat treating practice.

For all standard alloy analyses under manufacture and for special steels of unusual analysis, a 4 x 4-inch billet, located well down in the ingot, is selected from such heats coming through the mill as are rolled to this section. For each analysis this procedure continues until billets have been secured from not less than three, and frequently from five different heats. A 30-inch length of each billet is sent to the laboratory and etched with hot hydrochloric acid on each end. The etchings must show no segregation or

A paper presented before the Indianapolis Convention of the Society. The author R. M. Bird is Engineer of Tests, Bethlehem Steel Company, Bethlehem, Pa

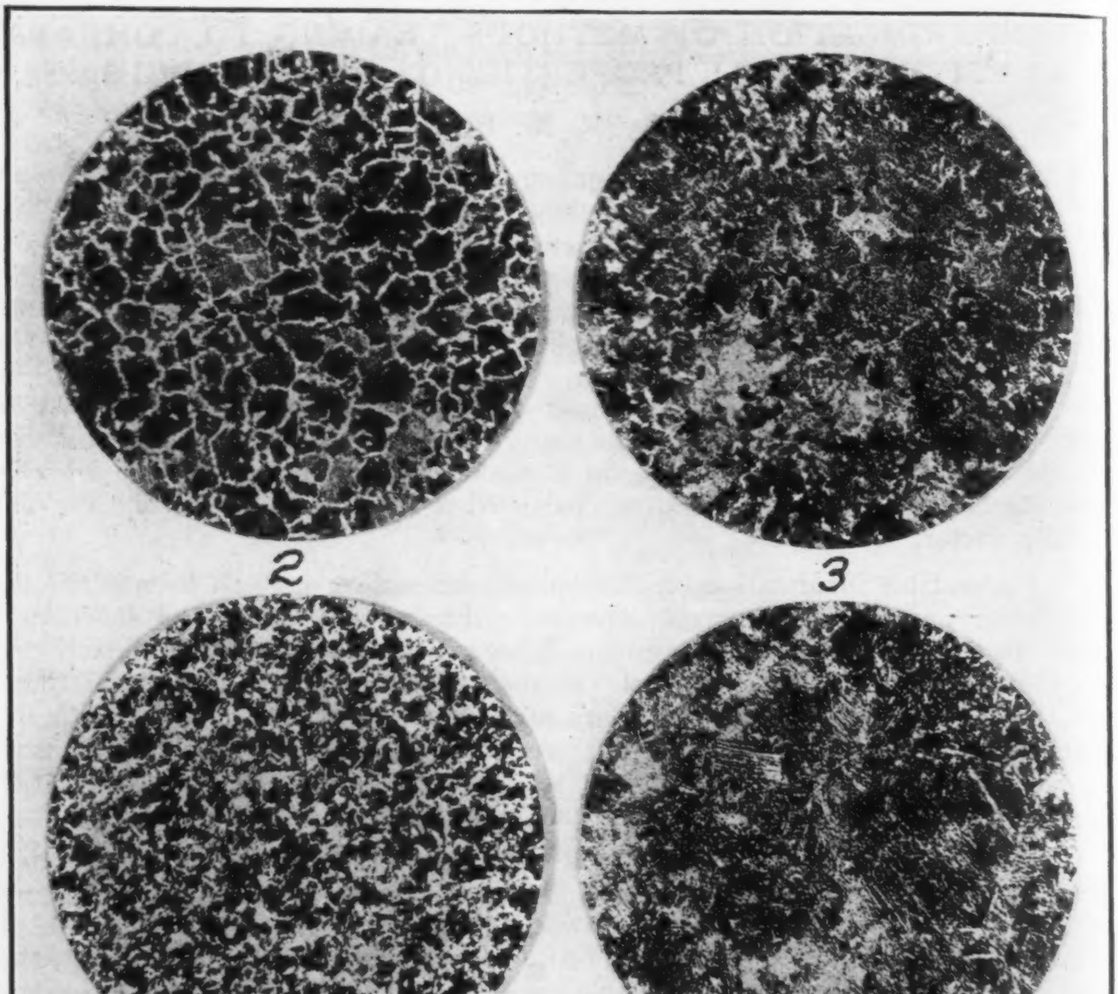

Fig. 1 Drill and specimen which has been sampled for chemical analysis. Fig. 2 Photomicrograph showing a satisfactory structure after quenching and tempering. Fig. 3 Photomicrograph revealing excessive segregation. Such a specimen would be rejected. Fig. 4 Shows the microscopic structure of a specimen which was quenched at too low a temperature. Fig. 5 Shows the microscopic structure of a specimen which was quenched at to high a temperature. Fig. 6 Photomicrograph of a specimen quenched at the proper temperature. Fig. 7 Tensile test specimen with Brinell impression on ground surface.

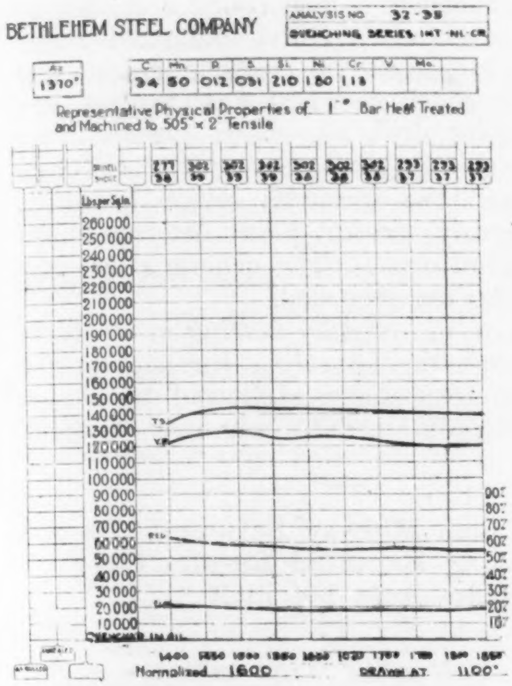

Fig. 8 Representative physical property chart of 1 inch round bar of chrome nickel steel normalized, quenched in oil and drawn. Quenching temperatures used as variable. Standard tensile test specimens were used.

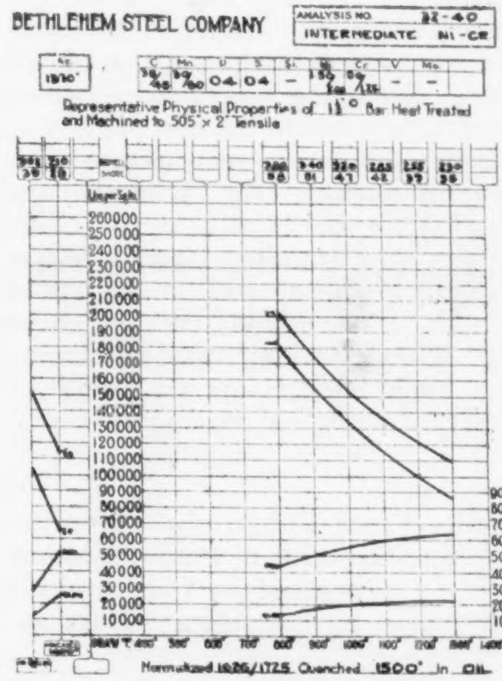

Fig. 9 Representative physical property chart of 1½ inch round bar of chrome nickel steel normalized, quenched in oil and drawn. Drawing temperatures used as variable. Standard tensile test specimens were used.

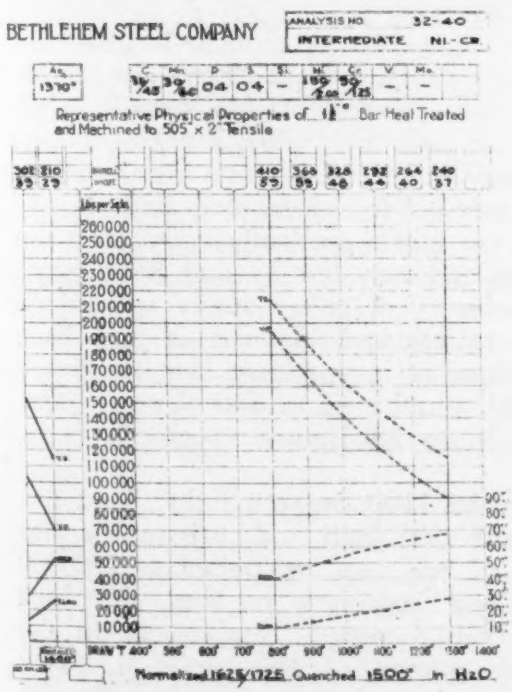

Fig. 10 Representative physical property chart of 1½ inch round bar of chrome nickel steel normalized, quenched in water and drawn. Drawing temperatures used as variable. Standard tensile test specimens were used.

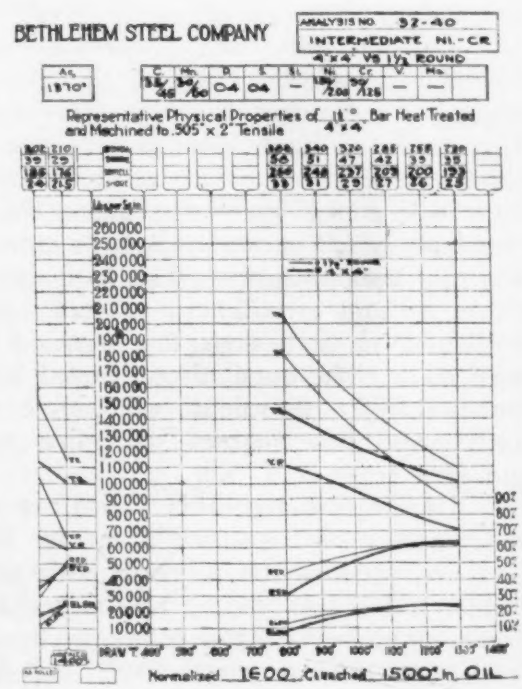

Fig. 11 Representative physical property chart of 1½ inch round bar compared to 4 x 4 inch billet of chrome nickel steel normalized, quenched in oil and drawn. Drawing temperatures used as variable. Standard tensile test specimens were used.

excessive slag. The adjacent billet is then rolled to 1 inch round and sheared to mill lengths. The ends of these bars are polished and examined under the microscope, and, when accepted, are inspected for surface cracks and seams. From the acceptable 1 inch rounds check chemical analyses are run on drillings taken radially with a taper point drill, of width greater than 1 inch, to a sufficient depth so that the drillings shall represent a full half area of section. Fig. 1 shows a drill and the specimen which has been sampled for chemical analysis. Simultaneously, critical point determinations are run on a standard transformation point apparatus. The general characteristics of the curves and the definite AC points are recorded.

The 1 inch rounds are then normalized or annealed by heating in whatever large hollow forging may be coming through the annealing furnaces at the time, to a temperature of usually 1650 degrees Fahr., followed by air or furnace cooling as the requirements of the container forging may demand.

Table I

Results From Longitudinal Specimens Taken Midway Between Axis and Surface of 4 x 4 inch Section Showing Expected Results Expressed in Percentage of Results from 1½ inch Round Bars as Shown in Fig. 11

	Drawing Temperatures					
	800	900	1000	1100	1200	1300
	Per cent					
Tensile Strength	72	75	80	82	89	91
Elastic Limit	61	67	71	74	78	82
Reduction Area	70	84	95	98	102	102
Elongation	69	81	100	110	110	113
Brinell	76	84	78	85	85	90
Scleroscope	77	84	81	81	82	86

To determine the proper quenching temperature, 5-inch lengths are heated in an electric furnace to temperatures ranging from below the known critical point, increasing by 100 degree Fahr. increments, to usually 1700 degrees Fahr. Each piece is held one hour at heat and, when cracking is not expected, is quenched in water or otherwise, in oil. The time consumed in transferring the specimens from the furnace to the quenching bath is approximately 20 seconds. Both water and oil tanks are sufficiently large so that the temperature of the bath is maintained between 70 and 85 degrees Fahr. without circulation. Pieces when submerged, either singly on end or separated in a basket, are continuously raised and lowered in the bath until cold. The quenching oil used is the same as in our large heat treatment tanks, being a petroleum oil, single refined, purchased to 340 degree Fahr. flash point, 380 degree Fahr. fire point, 26 to 28 Baume specific gravity, and free from acid.

All specimens of this series are drawn to 1100 degrees Fahr., held one hour, and cooled uniformly in air. Standard .505 inch x 2 inch tensile test bars are machined concentric with center of bar and are pulled in 100,000 pound universal testing machine. Each test specimen is then examined microscopically and the microstructure is then recorded. Decision as to the proper quenching temperature for 1 inch rounds of this stock is based upon a study of the physical property test results, combined with the microscopic report and the observed critical points. Photomicrographs in Fig. 2 to Fig. 6 show a satisfactory structure and four unsatisfactory structures resulting from the heat treatments which were applied.

The wide quenching range found in many alloy steels is surprising. Publicity has been given to this point in connection with chromium molybdenum steels. We find the range equally wide for the chromium nickel steels.

Sometimes we are still in doubt as to the proper quenching temperature. In such cases we quench more samples over a range of 200 degrees Fahr. by 50 degrees Fahr. increments. With the quenching temperature settled, sufficient pieces are prepared to cover a range of draws from 800 degrees Fahr. to

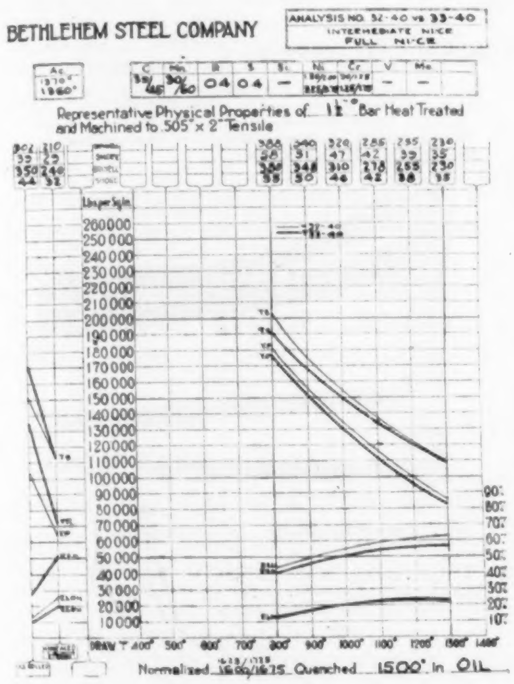

Fig. 12 Representative physical property chart comparing 1½ inch round chrome nickel steels of high and low alloy content. Steels were normalized, quenched in oil and drawn. Drawing temperatures used as variable. Standard tensile test specimens were used.

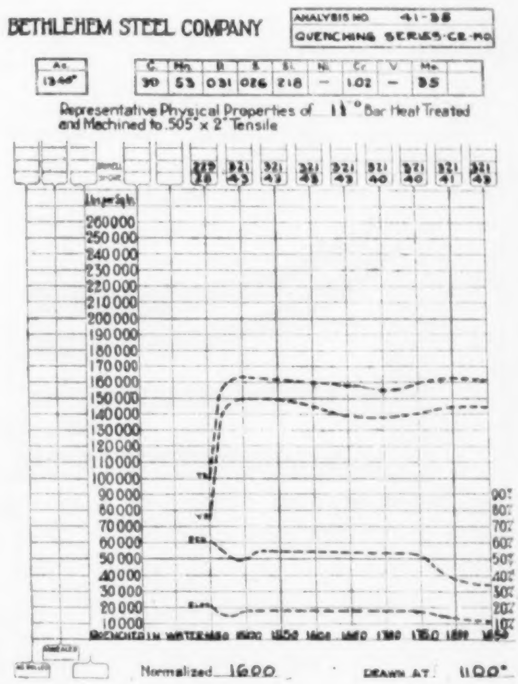

Fig. 13 Representative physical property chart of 1½ inch round bar of chrome molybdenum steel normalized, quenched and drawn. Quenching temperatures used as variable. Standard tensile test specimens were used.

1300 degrees Fahr. by 100 degree Fahr. increments, following an oil quench. A similar series is quenched in water on such analyses as will stand such drastic treatment. Tensile tests from these pieces form the ground work for our chart.

The longer threaded end of each broken test piece is filed and ground on the side to below the bottom of the threads, and Brinell and scleroscope readings are taken on this prepared surface as far as possible from the quenched end. A tensile test specimen so treated and tested is shown in Fig. 7.

The Brinell and scleroscope figures are not influenced by "end treatment," and represent the 1 inch round bar at half radius, resulting in more representative and consistent readings than those secured on or near the surface of the bar as heat treated. The data thus obtained are visualized by plotting upon a chart which, because of its simplicity we have adopted as a standard. As these charts are printed on tracing paper they can be reproduced as blue prints, or vandykes. Furthermore, for convenient comparison of different curves, one sheet can be superimposed upon another. Oil quenched tensile properties are shown as full lines; water quenched results ar dotted. Charts showing the physical properties of several alloy steels are

included under Figs. 8 to 13 inclusive. When three or more separate and distinct sets of curves from as many different heats of a given analysis show the same general characteristics, it is concluded that such physical properties are representative of 1 inch round bars from carefully selected material of that chemical analysis.

Comprehensive data on the effect of size as it influences the physical properties of heat treated steels are not yet available. Figs. 14 and 15 show the effect that mass has upon the physical properties of nickel chromium

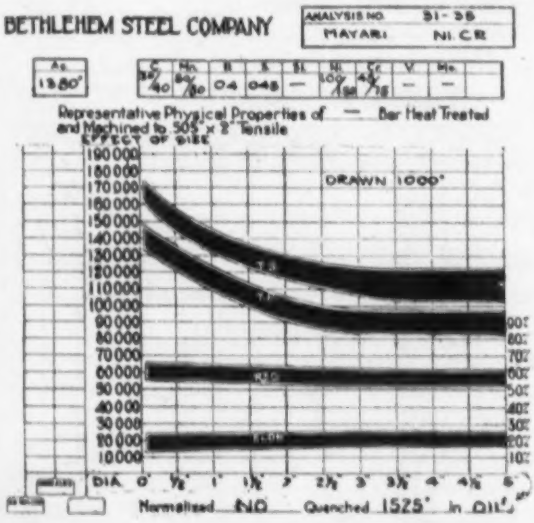

Fig. 14 Representative physical property chart showing the effect of size on the physical properties of heat treated chrome nickel steel using Mayari ore.

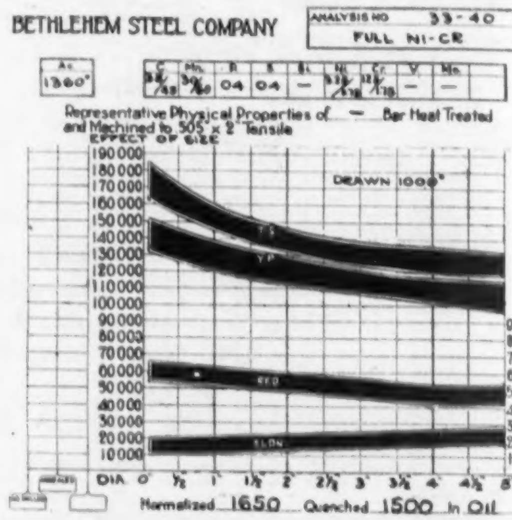

Fig. 15 Representative physical property chart showing the effect of size on the physical properties of heat treated chrome nickel steel.

steels. Excluding abnormally large forgings, seldom specified commercially of alloy steels, it would seem that above 5 inches in diameter or 5 inches square the physical values change but little with increasing size. As the sections decrease, especially under 2 inches, the elastic limit, tensile strength and reduction of area curve up sharply, with a corresponding decrease in elongation.

Paralleling the procedure with the 1 inch rounds, a more restricted series is run on the 4 x 4 inch billets. The selection of 4 x 4 inch sections, which with our operations is a convenient size, represents a point in the curve beyond which the increments of change are small. For these we quench in 11 inch lengths, and locate the test at middle length and at half radius. Table I shows the percentage of the figures shown in Fig. 11 that can be expected at a point midway between axis and surface of a 4 x 4 inch section.

The resulting curves are compared with the 1 inch round charts in two ways:

1st—By superimposing 4 x 4 inch chart on 1 inch round chart.

2nd—By tabulation of percentages of physical properties over the 1 inch round stock as a base.

Conclusion

In conclusion the writer wishes to point out that this paper has been offered with the hope that more thought will be given to the need for what is expressed in the title of the paper—"Standardization of Methods Leading to Comparative Physical Properties of Alloy Steels;" and with the suggestion that the American Society for Steel Treating might well take up this work in its program for the coming year.

THE HIGH COST OF CARBONIZING

By T. G. Selleck

THE use of the carburizing process is, no doubt, greatly restricted because of its excessive cost. There was a time when manufacturers kept aloof from it as much as possible because of its unreliability, but that hindrance to its successful use having been largely removed by more scientific methods of application and the improvements made in shop equipment, such as heat recording and controlling instruments, and closer laboratory supervision, it is found that there is added reason to avoid its use in the increasing cost of application.

This increasing, or at least increased, cost of application is to some extent due to the improvements mentioned, and it may be fairly claimed that the increased cost is offset by the improved quality of the carbonized work produced and saving in the matter of loss of parts, as a result of carburizing failures. But the real cause of the high cost of carburizing lies in certain conditions attending every carburizing operation, whether performed under the most modern methods and with the use of modern equipment, or in the ordinary crude way without scientific supervision.

A Study of Costs

A close study of the process and methods of its application reveals the fact that, in general, the methods employed are decidedly extravagant, from the point of cost, and have attached to them certain "fixed charges" that establish the foundation for excessive cost. These fixed charges are common to all carburizing operations, but only those wherein pots and boxes are used will be considered in this consideration of the subject, since other methods are not used sufficiently to obtain any accurate information as to average costs. These fixed charges are classified as follows:

1. The cost of primary heating; that is, raising the temperature of the cold contents of the pot, or box, to a carburizing temperature.

2. Wear and tear of equipment, or depreciation, except for pots and boxes.

3. Cost of pots, or other containers.

The first item, the cost of primary heating, is combined usually with the second item and calculated as so much per hour per furnace, and the charge allowed averages about one dollar per hour. This also includes labor and will, of course, vary according to the number of furnaces in proportion to labor employed; but one dollar per hour is considered a fair average. The third item must be considered by itself because it is determined according to the character of the metal in the container used, the weight of the container in relation to weight of the parts and the number of hours the container is in service. The cost of primary heating is the heaviest part of all the expense of carburizing a charge of steel parts, since the time required for such heating has proven to be, both by laboratory test and actual shop practice, an average of about 2/3 of the total furnace time; this means that for a twelve hour operation, 8 hours is spent in primary heating and 4 hours given to the application of the desired carburizing temperature.

The causes underlying this excessive fuel cost for primary heating are

A paper written for TRANSACTIONS. The author, T. G. Selleck, is consulting metallurgical engineer, Chicago, Ill.

found in the manner in which the process is applied and is well illustrated in the specifications sent out recently by a large motor manufacturer seeking quotations on equipment for carburizing steel gears.

Ten single chamber or five twin-chamber furnaces of approximately the following dimensions are required—4 feet wide, 7 feet 6 inches deep and 24 inches to the spring of the arch, from the hearth. These five or ten furnaces, either electric or coal-burning, are to be used to carburize approximately 2200 gears in 12 hours. Each furnace will have a capacity of 15 pots, each pot containing 15 gears, and the specifications say "The charge per pot will be made up as follows:

Cast steel pot	weight	116 pounds
Fifteen gears	weight	37 pounds
Carburizing material	weight	27 pounds
Total weight per pot	weight	180 pounds"

From this it will be seen that 180 pounds of material are to be heated in order to heat 15 gears weighing about 1/5th, or 20 per cent of the total. The estimated time required for primary heating being 8 hours in this case and the estimated cost of furnace operation being $1 per hour, it is apparent that the fixed charge for primary heating in this case is $8 for 555 pounds of gears, or 1.4 cents per pound. The total weight of 15 pots is 2700 pounds and this mass of material must all be heated through before the gears can be affected by the carburizing material: This is what is meant by primary heating and this specification illustrates clearly one of the causes of the high fixed charges in carburizing. More than 3 times the weight of the gears is contained in the weight of the pots alone so that the fuel used during the entire operation is but 1/3 applied to the actual carburizing of the steel even after the primary heating.

The deterioration of pots in this case will amount to 0.55 cents per pot for the 12 hours of actual use or an additional 1.5 cents per pound, and is based upon one thousand hours life of pots and the lowest price at which such pots may be purchased. Thus we have 3 cents per pound in fixed charges in every average carburizing operation for primary heating. To this must be added fuel and labor cost for the actual carburizing period and the regular "overhead" charge to complete the actual cost of carburizing and for the finished product the additional cost of subsequent heat-treatment. These figures are for operations carried out under the most favorable conditions; only in plants where the strictest supervision of furnace practice is maintained can it be hoped to keep these primary costs within the limits given here.

Close Supervision Necessary

In many carburizing plants, sometimes maintained by large corporations, where other manufacturing processes are given close supervision and rigid care in all details, there is found a slackness and indifference that is appalling when the importance of the work being done is considered. Equipment is most shamefully abused and allowed to deteriorate until the production of a uniform and high quality product is impossible. Then it is that trouble presents itself, parts fail under final inspection, or what is worse, in service, and the manufacturer finds it necessary to call in some outside help to locate the cause of his failures. One recent case indicates how the carelessness and indifference of the supervisor of the carburizing and heat-treating plant of a very large factory cost his employers a considerable monetary loss besides a

heavy loss in business.

Being called to the plant in an advisory capacity, the writer was amazed to find an utter disregard of the simplest rules of care in the use and treatment of equipment. The carburizing parts being quenched from the pots at a temperature of approximately 1650 degrees Fahr. it is easily understood that a malleable iron pot would be more or less soft and easily distorted by rough handling, and it would seem that provision would be made for handling in such a way as to prevent, as far as possible, the deforming of them. But in this case the pots, as soon as emptied were hurled a distance of at least 10 feet on to a cement floor covered with steel plates; the result was a lot of pots of every conceivable shape with covers in equally bad condition, after only one or two usings. It was partly because of the use of these distorted pots that complaints of failure of their carburized parts in service, a thousand miles away, were coming too frequently to the notice of the manager who finally set about an investigation by a disinterested engineer.

In this plant a cost of 3.5 cents per pound for carburizing was claimed but if the company were obliged to purchase their pots the cost would easily be doubled, but having their own foundry, they were not allowing themselves any profit on them, and thus reckoned their costs below what would be the average. The same abuse of furnaces was noted. Scale from the pots was allowed to accumulate in the furnaces, until the gas flames from the combustion chamber came in streaks, striking some of the pots with a directness and severity that caused over-heating, and so remote from others that the indirectness of the heat caused a lack of temperature that was reflected in scanty penetration of parts contained in them.

These deplorable conditions are due to that most dangerous of all factors employed in carburizing and heat treating "the human element." More than fuel, more than carburizer, more than the checking and calibration of the pyrometer, does this human element need constant watching and checking up, for it is the factor wherein originates every failure that occurs and causes the unnecessary cost that is common in the maintenance of equipment.

Nothing has been said about the cost of carburizer as related to the high cost of carburizing, but if the proportion of carburizer by weight to the weight of steel parts is to be maintained in all cases as it is given in the specifications referred to, then we must add a generous amount to our already high estimate. However such a proportion is so far above the average that it is not to be considered. If we are to reduce the high cost of carburizing it is apparent from our consideration of the subject that we must begin by reducing these fixed charges for primary heating and in some way eliminate or at least greatly reduce the cost of pots and boxes.

The solution of the problem does not lie in the improvement or discovery of alloys that will give longer life to the containers but the development of methods that will entirely eliminate them and bring the work into more intimate contact with the source of heat. Such methods will not only result in more economical production but will make possible a higher quality of work than can be produced by the pot method. Already automatic furnaces are operating along these lines in a limited field and the field can easily be broadened by the application of some scientific study of the mechanics of the process. We must also get away from present methods, for the elimination of the danger of the human element: we can not get entirely away from it but we can so reduce it that it can not be the menace it is at present. Automatic furnaces, automatic temperature control and automatic quenching sys-

(*Concluded on page* 1236)

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment—Members Submitting Answers and Discussions Are Requested to Refer to Serial Numbers of Questions.

NEW QUESTIONS

QUESTION 41. *Is the X-ray examination of steels commercially practicable?*

QUESTION 42. *Why should high speed steel be delivered only in the annealed condition?*

QUESTION 43. *What is the role of Chromium and Vanadium in steel?*

QUESTION 44. *Is it advantageous for the purchaser to conduct a test on various brands of high speed steel before deciding upon placing his contract?*

QUESTION 45. *What is the value of testing finished tools with a file?*

OLD QUESTIONS AND ANSWERS

QUESTION NO. 8. ***What is the effect of high and low silicon in tool steel?***

ANSWER. The greater the percentage of silicon that a tool steel contains, the greater will be the brittleness of the steel. If the content of silicon exceeds one or two per cent the steel will be brittle, in the case of the higher carbon steels, even though the steel be unhardened.

The presence of silicon to the extent of 0.20 per cent, in tool steel or in fact in any steel, which does not contain the nonferrous elements which prevent the formation of graphite, greatly promotes the formation of black steel, that is, steel containing all or nearly all of its carbon in the graphitic form. For example, a steel containing 1.15 per cent carbon or more with a silicon content of 0.20 per cent, is peculiarly liable to black fracture when held for a number of hours at 1300 degrees Fahr.

For the keenest edged tools that possess the most strength and toughness when in the hardened state, there is strong evidence that the lower the silicon content the better, other things being equal. The presence of silicon in crucible steel is unavoidable as under the most perfect reducing conditions of crucible melting, a little of the carbon (graphite) plus silica from the wall of the crucible is reduced to silicon carbide which is absorbed by the molten

steel thereby adding silicon as well as carbon to the steel. Hence tool steels produced under the most perfect reducing conditions of the crucible melting process, having the lowest silicon content commercially practicable, are the highest quality steels for the keenest cutting edges.

As in the case of all steels, the increase of the silicon content renders tool steel more resistant to oxidation at high temperatures and to the attack of acids.

QUESTION NO. 23. Why is it that a piece of hot rolled steel, of a given composition, will not harden in oil after carbonizing to the degree

ANSWER. By E. W. Ehn, metallurgist Timken Roller Bearing Co., Canton, O.

At the plant with which the present writer is connected extensive experiments were made some years ago with plain carbon steel in order to determine whether mechanical work on the steel previous to the carburizing operation had any influence on the results obtained in the hardening, and it was found that no such difference was obtained whether the steel was hot rolled, cold drawn or forged. The statement that the hardening was made in oil indicates that the experience referred to in Question No. 23 was obtained with an alloy steel, but there is no reason to believe that a variation in the hardening properties in carburized work will be caused even in this steel by a forging operation previous to the carburizing.

That different steels of similar chemical composition after carburizing respond in a different way to a hardening operation is, however, true and this subject has been dealt with at considerable length in several recently published papers. If different results are obtained in hardening of carburized steel of similar analysis, it is fairly certain, provided that the carburizing and hardening conditions are identical, that this is due to the steel itself and the best method of checking this point is a microscopical examination of the carburized specimens before hardening. A fine grained steel with curly cementite in the hypereutectoid zone indicates a poorly deoxidized steel that will give trouble in hardening, whereas, a good steel will show a hyper eutectoid zone with large solid areas of pearlite and clean-cut cementite lines along the grain boundaries. For details on this subject see answer to Question No. 24 in TRANSACTIONS of American Society for Steel Treating, July, 1922.

QUESTION NO. 26. Does the presence of pearlite in the decarburized zone of a malleable iron casting effect the resistance of this casting to shocks?

ANSWER. By H. A. Schwartz, Manager of Research National Malleable Castings Co. A categorical answer to this question is impossible since quantitative impact tests on identical material differing only with respect to pearlite in the edge are not available. The experimental difficulties of preparing such comparative materials in a form suitable for impact testing appear to be very great.

It is reasonably well established that a white rim increases the tensile strength and decreases the elongation under static loads. Whether the net

result is an increase or a decrease in energy of rupture is not established.

Casual observation in inspecting castings by breaking off test lugs would lead to the conclusion that in extreme cases, at least, the presence of pearlite decreases shock resistance. Only direct experiment, however, would permit one to speak with confidence on the point.

QUESTION NO. 27. What is the function of the high phosphorus and the high sulphur content in the so called automatic screw stock steel?

QUESTION NO. 30 How do the physical properties of a chrome molybdenum steel vary from the physical properties of a chrome vanadium steel after suitable heat treatments have been given to each?

QUESTION NO. 32. In choosing a carburizer, what are the essential features that should be considered?

QUESTION NO. 35. What is the difference between red annealed and blue annealed sheet steel?

QUESTION NO. 37. What is the role of vanadium in steel?

ANSWER. From a paper by G. L. Norris, presented before the Twentieth Annual Meeting of the American Society for Testing Materials. The metallic element vanadium is one of the fifth group of chemical elements which includes phosphorus, arsenic, antimony, nitrogen, etc. It has an atomic weight of 51.06; specific gravity of 5.5, and melts at 1680 degrees Cent. It is grayish-white in color, non-magnetic, has high electric resistivity, is the hardest of the metallic elements, and the most difficult to reduce. It has not been produced in the pure metallic state. Although discovered in 1830 and soon found to be widely distributed, its known occurrences were in such small quantities that for many years vanadium was considered one of the rarest elements.

The first metallurgical application of vanadium appears to have been in 1896, when it was used in making several heats of steel at Firminy, France. The results of this test showed a remarkable superiority of the vanadium steel in physical properties. Under the same heat treatment, the vanadium steel showed an increase of 44.8 per cent in elastic limit and 31.5 per cent in tensile strength, with slightly lower percentage of elongation but greater reductions of area.

The following discussion will be confined almost entirely to the consideration of pearlitic-vanadium-ternary steel, or simple carbon-vanadium steel, and will not more than briefly touch on the quaternary-vanadium steels. First, however, the writer wishes to touch briefly upon a still somewhat

prevalent popular idea that vanadium is a powerful scavenger, and that the beneficial effects of its use in steel are principally due to its removal of minute, residual amounts of oxygen and nitrogen from the steel. It has even been advanced by some individuals that when all the vanadium added has been completedly used up in scavenging, and none remains in the steel, all the improvement or beneficial effects possible have been accomplished; despite the fact that there is an increase in the mechanical proprties of the steel with increasing amounts of vanadium present, and that vanadium has equally as great beneficial effects in steels made under reducing conditions such as crucible and electric furnace steels, as in the case of steels made under oxidizing conditions like open-hearth and Bessemer steels. While it is true that vanadium oxidizes readily and will combine with nitrogen, its value as a scavenger is negligible, as there are much cheaper metals that are as effective, or perhaps more so.

The remarkable effects of vanadium on steel are due entirely to its presence in the steel as an alloying element, and its influence on the other constituents with which it is in combination. When added to steel it is found in both the main constitutents, ferrite and pearlite, but principally in the latter. Only a few hundredths of one per cent of the vanadium combines with the ferrite. This minute amount, however, appears to increase the strength, toughness, hardness and resistance to abrasion of the ferrite. Nearly all the vanadium, however, is found in the pearlite, in chemical combinations with the cementite, as a compound carbide of vanadium and iron in the case of ternary steel, and as more complex carbides in the case of quaternary steels.

Vanadium replaces the iron in the cementite or the carbide by increasing amounts until finally when the percentage of vanadium is about 5 per cent all the iron has been replaced by the vanadium. The vanadium-containing cementite is not as mobile as ordinary cementite and consequently does not segregate into as large masses, but occurs in relatively minute particles and, therefore, is more uniformly distributed. It does not, consequently, readily occur as lamilar or thin plates in the pearlite, but in a granular or sorbitic condition. This strong tendency of vanadium to form sorbitic and even troostitic pearlite, is doubtless one of the reasons for the mechanical superiority of steels containing vanadium, not only statically but dynamically.

Vanadium carbide is not as readily soluble on heating as iron carbide, and consequently vanadium steel requires a higher temperature to dissolve the cementite and put the steel in the austenitic condition for quenching.

The presence of vanadium does not raise the Ac1 and Ar1 points more than about 10 degrees Cent., and repeated heatings do not seem to lower the Ar1 point. The Ac2-3 and Ar2-3 points are raised somewhat more and continue to rise with increase in percentage of vanadium.

The effect of vanadium on the physical or mechanical properties of steel increases with the percentage of vanadium until about 1 per cent is present, after which there is a decrease, even in the case of quenched steels, and with 3 per cent or more of vanadium the steel is actually softened on quenching until unusually high temperatures are reached, say about 1300 to 1400 degrees Cent.

Vanadium steel hardenite has a greater thermal stability, or power to withstand elevated temperatures without softening or breaking down or separation of cementite. This property is responsible for the great improve-

ment in high-speed steels, through the addition of vanadium to stand up longer under the high temperatures developed at the point of the tool in taking heavy cuts at high speed. Percentages of vanadium as high as 3.50 have been successfully used in high-speed steel, and 1.50 to 2.50 per cent are not uncommon, although only a few years ago the percentage ranged from 0.30 to 0.75, and it was thought that the addition of over 1 per cent gave very little additional advantage. The improvement in high-speed steel through the use of vanadium has borne an almost direct relation to the percentage of vanadium present, and is considered to be from 60 to 100 per cent.

In the case of carbon-vanadium tool steel the use of vanadium has proved almost equally beneficial, although at present only about 0.2 per cent of vanadium is used in such steel. It has a wider quenching range—that is, can be heated higher without injury,—hardens deeper, retains cutting edge longer, and is very much tougher and stronger. A bar of 1-per-cent carbon tool steel containing 0.25 per cent vanadium, quenched and drawn back at 400 degrees Cent., will bend 90 degrees without failure whereas a similar steel without vanadium will bend only about 20 or possibly 30 degrees. Comparative compression tests of such tool steels with like tempering or draw back gave on 1¼ inch cubes, 490,000 pounds for the vanadium steel and 278,000 pounds for the steel without vanadium. For battering tools, such as pneumatic chisels, sets, calking tools, rock drills, etc., vanadium tool steel possesses marked superiority on account of its combination of hardness, strength and toughness.

One of the principal applications of vanadium steel has been for steel castings, particularly for locomotive frames. The composition of the steel is the same as usual for such castings, excepting for 0.15 per cent or more vanadium. The addition of this small amount of vanadium increases the elastic limit of the annealed castings 25 to 30 per cent without lowering the ductility. The tensile strength is not increased proportionately in the case of thoroughly annealed castings, but is usually 10 to 15 per cent greater.

There is also doubtless a great future for vanadium-quaternary steel castings, both annealed and heat-treated—particularly the latter—for, as in the case of forged or rolled quaternary steels, the improvement in the mechanical properties from the presence of vanadium would be much greater even than in the case of simple carbon-vanadium steel. The value of vanadium in simple carbon forging steels has been over-shadowed by the greater mechanical properties of the vanadium-quaternary steels, such as chrome-vanadium, yet they have mechanical properties equal to those of ordinary 3-per-cent nickel steel under like conditions. Excepting where the very high physical properties obtainable from quaternary steels are desired, carbon-vanadium steel can be used to advantage, especially for large forgings.

This steel presents fewer manufacturing difficulties than quaternary steels. It is less liable to losses from shrinkage cracks and checks in the ingot, and to heating and cooling strains in the forging and heat-treatment operations. It requires no more special care in handling than ordinary carbon steel, and is worked with equal facility.

Carbon-vanadium forging steel in the normalized condition, which may be described as annealed for grain refinement, has physical properties superior to those specified for heat-treated carbon-steel forgings. This simple treatment alone, therefore, gives physical properties sufficiently high for a great number of forgings that would otherwise have to be quenched and tempered.

A large field for annealed or normalized carbon-vanadium steel is its

use for locomotive forgings. It is generally conceded that there is need of a steel of greater strength, not only to meet present conditions, but also to permit of reducing sections of reciprocating parts to obtain better counterbalancing. To meet this requirement, the railroads several years ago turned to heat treated carbon and heat-treated alloy steels, notably chrome-vanadium. The use of heat-treated locomotive forgings has not proved altogether satisfactory for a number of reasons. One objection to the use of these forgings is the lack of heat-treating equipment in most of the railroad shops. This operates particularly in repair work where for any reason the forging has to be locally heated to straighten, stretch or shorten, destroying thereby the effect of the original heat treatment and producing inequalities which may result in failure. Probably no other class of forgings is subject to as abusive use as locomotive forgings, and under such conditions ordinary heat-treated forgings have not been found reliable. For these and other reasons annealed forgings are preferred. Consequently, as steel that could give in an annealed condition physical properties equal to or even better than those specified for heat-treated carbon-steel forgings, would prove very desirable.

Nickel-Vanadium steel, while having possibly even higher tensile properties than chrome-vanadium steel, is considerably more expensive and has not been found to meet all conditions as satisfactorily as chrome-vanadium steel. It does not appear to have as high a resistance to shocks and repeated stresses.

QUESTION NO. 38. *What regulations are recommended to reduce the fire hazzard of quenching tanks?*

QUESTION NO. 39. *What happens to a piece of steel when it is tempered or drawn back after quenching from above the upper critical point?*

ANSWER. By Walter M. Mitchell, Philadelphia, Pa. Above the upper critical point, which is the limit of the critical range, iron and carbon mutually dissolve forming a solid solution which is stable only at temperatures above this range. If this solid solution is cooled slowly through the critical range it will decompose with the separation of the iron and carbon, (the latter in the form of cementite), which decomposition requires a definite length of time for its completion. If, however, the solid solution is cooled suddently, as by quenching, sufficient time for decomposition will be denied, and the steel will be retained, "frozen" as it were, in the condition of solid solution. This is an unstable condition when existent at ordinary temperatures, and thus we have the steel in a condition which is stable at one temperature, existing at some other temperature at which it is not stable. Such a condition will tend to become stable if the proper agent is provided which will overcome the rigidity of the cold metal. This agent is heat; and its effects in the operation of tempering is to produce plasticity or "loosening" which will permit relief from strain and atomic adjustment; the metal approaching more and more as the temperature, or the time held, is increased, the normal condition; i. e., that which is stable at ordinary temperatures.

As a comparison we may imagine a rubber band, which has been stretched and by some means frozen in the stretched condition—this represents the

quenched steel. If a slight heat is applied so as to "thaw" the rubber it will gradually return to its normal condition; the higher the temperature the more quickly will this take place.

Now as regards the effect of tempering on physical properties. In the quenched condition steel consists largely of the constituent martensite. Martensite is very hard, space will not admit of the discussion why this is so, other than to say that its hardness is due possibly to two causes: the greater attraction between unlike atoms (iron and carbon) resulting from the hetrogeneous atomic mixture in the solid solution, which is simply a particular case of the general rule that metals are hardened and strengthened by the addition of elements which dissolve in them to form solid solutions; and the extreme fineness of grain structure developed during the quenching operation. Now if the solid solution is decomposed in the tempering operation the result will be a coarsened grain structure and increased separation of the iron and cementite particles, which will be accompanied by increased softness and ductility. With the progress of the tempering operation there will be formed a series of transformation products which are individually characteristic and identifiable under the microscope, and possess definite physical properties. These products have been named troostite, sorbite, and pearlite, and represent advancing stages in the separation of iron and cementite; each one being a decomposition product of the former, and hence softer and more ductile than it. Thus the object of the tempering operation is to allow the decomposition of the solid solution to proceed to the proper degree, and thus produce that constituent in the steel which will have the desired physical properties.

ANSWER. By H. J. French, Physicist, U. S. Bureau of Standards. The effects observed in tempering hardened steel will depend upon its composition, size and shape, details of the method of hardening, etc. Therefore the very general nature of the question precludes an adequate reply in the limited space available except by referring the inquirer to well recognized books and reports related to the heat treatment of steels in which very complete discussions will be found.

It may however, be helpful to consider briefly from a theoretical standpoint, some of the principal effects of tempering carbon steel, of such composition, size and shape and quenched in such a manner from above the upper critical range, that it has been "completely hardened throughout." Because such steel shows a structure called martensite when examined under the microscope it is called martensitic or completely hardened steel by the metallographist. The rapid cooling required to produce this condition has left the metal in a highly stressed condition and while there is a tendency for readjustment and relief of these stresses such changes proceed slowly, at least after a brief space of time, because of the regidity of the hard-at least after a brief space of time, because of the rigidity of the hardened steel.

When heat is applied, for example at 100 degrees Cent. (212 degrees Fahr.) the metal becomes more plastic and somewhat more advanced readjustment is possible so that the first effect observed is a change in dimensions of the hardened steel. As the temperature is further increased the dimensional changes continue. When the steel is tempered at about 250 degrees Cent., a decrease in hardness and a partial change in structure of the martensite to that called troostite are observed. With increase in tem-

pering temperatures to just under the transformation range, the steel becomes progressively softer, more ductile, and continues to change in dimensions; the full martensitic structure gradually disappears until the steel becomes troostitic, and then sorbitic, as is shown in Fig. 1. Accompanying these structural changes are a decrease in strength and elastic limit. Likewise changes in other properties such as electrical conductivity, density, magnetic properties, etc., occur but the limited space available does not permit

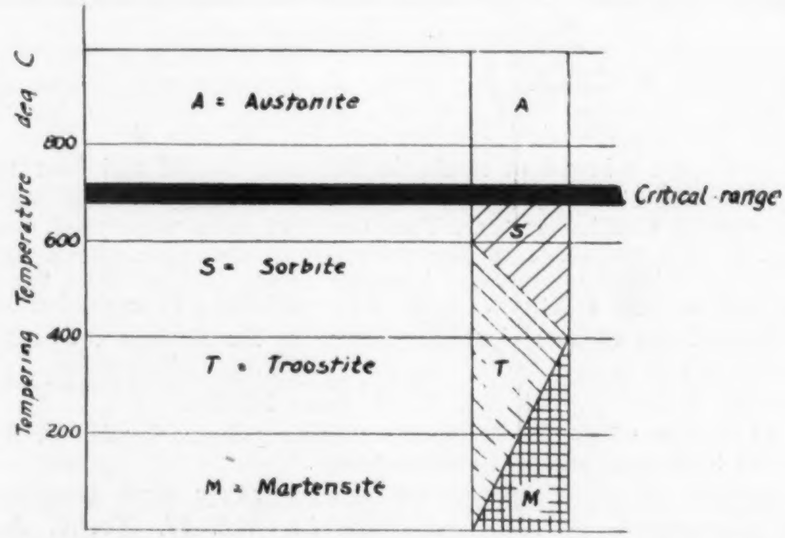

Fig. 1—Diagram depicting the tempering of hardened steel originally all martensitic. (After Sauveur).
Note: The distance—horizontally—within the block for any tempering temperature represents proportions of martensite, troostite, etc., theoretically present.

more detailed consideration of these effects. The important feature is that in hardening the steel the transformation which normally occur in slow cooling are largely prevented from taking place and the metal is considered to be in an unstable condition. Tempering permits the arrested transformations to advance more and more to completion as the temperature is increased.

If austenite is retained in quenching, (a condition which may readily be obtained in many of the alloy steels), changes upon tempering are complicated. When troostite is first formed one less stage in the advancement of the transformations to completion is observed.

Detailed discussion of the hardening and tempering of steels may be obtained from the following texts:

Steel and Its Heat Treatment. D. K. Bullens, Pub. John Wiley & Sons, New York, N. Y.

Metallography and Heat Treatment of Steel. A. Sauveur, Pub. Sauveur & Boylston, Cambridge, Mass.

Steel: Its Selection, Annealing, Hardening and Tempering. E. R. Markham, N. W. Henley Pub. Co., New York, N. Y.

QUESTION NO. 40. What is the influence of a low percentage copper content in steel?

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

RESISTANCE TO CORROSION OF VARIOUS TYPES OF CHRONIUM STEELS. By Henry S. Rawdon and Alexander I. Krynitsky, Physicist and associate physicist, Bureau of Standards. *Chemical and Meatllurgical Engineering*, Vol. 27, No. 4.

Several pure Chromium steels, in the cast, forged and heat treated conditions were observed during immersion in dilute hydrochloric acid and in aerated distilled water. Two types of tests were used, one for determining the resistance of the materials to corrosive attack by acid and the second being a simulated "weather" test. Tables show the effect of the various heat treatments upon their resistance to corrosion attack. The effect of the various elements present in the steels are discussed.

NOTES ON ACID ELECTRIC FURNACE PRACTICE. By C. W. Francis, *Iron Age*, Vol. 110, No. 6, pages 345-346.

A discussion of the steel foundry melting practice in the U. S. and the use of basic steel scrap in acid furnaces.

SCIENTIFIC SELECTION OF MATERIALS FOR FORGINGS. Special Correspondence, *American Machinist*, Vol. 57, No. 6, August, 1922, Pages 211-215.

A paper covering the selection of steel to suit the job including a discussion of the various testing machines and equipment used in determining the quality of the material. The importance of proper heat-treatment as supervised by the metallurgical laboratory.

STAINLESS STEEL AT HIGH TEMPERATURES. By H. J. French, *Iron Age*, Vol. 110, No. 7, August, Pages 404-405.

Stainless steel of 0.30 per cent carbon and 13 per cent chromium has been successfully used for valves operating at high temperatures. Curves are presented showing the physical properties of this type of steel under various temperatures. Photographs of fractures of this steel broken in tension are exhibited.

MALLEABLE CAST IRON. By Enrique Touceda. *American Machinist*, Vol. 57, No. 9, pages 321-325 August, 1922.

A discussion of the qualities of pure cast iron and steel as compared with the same qualities of malleable castings. A few photomicrographs of these metals are shown. A brief discussion of the melting, pouring and annealing of malleable cast iron together with its characteristics as finished for use.

THE DECOMPOSITION OF MARTENSITE INTO TROOSTITE IN STEELS. By Howard Scott of U. S. Bureau of Standard. *Forging and Heat Treating*, July, 1922, pages 296-299.

The effect of the alloying elements, manganese, silicon, nickel, cobalt, tungsten, chromium, vanadium and molybdenum, on the decomposition of martensite to troostite was determined by means of heating curves. Only three of these elements showed a marked effect, namely, manganese, silicon and chromium. The first named increased the intensity of the transformation, while the last two raised its temperature when present in in certain percentages. None of the alloying elements lowered the transformation and no general relation was found to exist between it and the higher critical point Ac_1. The significance of these data in regard to heat treatment and properties of alloy steel is discussed.

Comment and Discussion

Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Criticism in This Column—Members Submitting Discussions Are Requested to Give Their Names and Addresses

NEW FORMULA DERIVED

A recent communication from F. H. Baldwin of Bethlehem, Pa., contained the following comments in reference to the physical properties of S. A. E. steel No. 1045. Mr. Baldwin says:

"In reviewing the tabulation of the ultimate tensile strengths of steels, published by the Society of Automotive Engineers, it occurred to the writer that the relationship between the different values was governed by a circular function, and as a result he has become so interested in this matter that he has worked out this idea. Believing that readers of TRANSACTIONS might also wish to have this information, he is transmitting the formula covering S. A. E. steel No. 1045 in the hope that it may stimulate a discussion.

$$T = 110 + 15\frac{1}{2} \operatorname{Sin} (9 - t)\ 15^\circ$$

where T = Ultimate tensile strength / 1000
t = Drawing temperature degrees Fahr. / 100

Applying the formula to the tabulation, the following comparative results are obtained:

Drawing Temp. Degrees Fahr.	Ultimate Strength Pounds Pounds Per Square Inch Formula	Pounds Per Square Inch S. A. E.
400	125,000	125,000
500	123,400	123,500
600	120,950	121,000
700	117,750	118,000
800	114,050	114,000
900	110,000	110,000
1000	105,950	106,000
1100	102,250	102,000
1200	99,050	99,000
1300	96,600	96,500
1400	95,000	95,000

In presenting these figures the writer wishes it to be understood that he is simply offering an explanation of the relationship obtaining between the published values as given by the Society of Automotive Engineers."

PAPER CORRECTED

Attention has been called to the fact that an error existed in G. C. McCormick's paper entitled "Furnace Atmospheres and Their Relation to the Formation of Scale" published in August TRANSACTIONS, on page 1012. The second line should read "carbon monoxide present," and the sentence preceding the paragraph 'Conclusions,' should read:

> "It, therefore, appears logical to conclude that regardless of the presence of carbon monoxide in the furnace atmosphere, scaling will take place when the temperature is sufficiently high and the time of heating is sufficiently long."

Reviews of Recent Patents

1,410,566. Electric Furnace. William S. Hadaway, Jr., of New Rochelle, N. Y.

This invention relates to improvements in electric furnaces and especially to a new type of apparatus for obtaining high temperatures at low cost. One object of the invention is to provide a simple apparatus for supporting combustion wherein the temperature of admitted vapor is raised above the ignition pont of the fuel by electrical energy. Another object is to provide an automatic means for controlling the electrical energy for the heaters. A still further object is to provide means for admitting air to the combustion chamber where it may be combined with the flame and increase the efficiency of the apparatus.

1,414,366. Method of and apparatus for heat treating metallic articles. Harry P. Macdonald, Montclair, N. J., assignor to Snead & Company.

Method of heat treating metallic articles which consists in cutting off the heat and in quenching at approximately the end of the critical period.

1,414,489. Annealing and other furnace. Ralph C. Stiefel, Ellwood City, Pa.

In combination with a heating furnace provided with openings in opposite ends thereof, of a table immediately adjacent each end of the furnace on a level with the bottom thereof, a pair of connected work carriers movable on said tables and on the furnace bottom, and mechanism for drawing said work carriers simultaneously and alternately in opposite directions, said work carriers being spaced apart, and each having a total length less than the length of the furnace whereby when either thereof is in the furnace the other one is entirely outside the furnace on one of the tables for loading and unloading.

1,415,261. Process of case hardening articles. George C. Nixon and Frederick Charles Raab, Syracuse, N. Y.

The process of carburizing metal, which process includes covering the portion of the article to be carburized with adhering carbonaceous material under pressure sufficient to cause the same to rigidly adhere to the article and form a relatively thick layer thereon, and then heating the article with the carburizing material thus secured thereon.

1,416,006. Supporting apparatus for use in tempering furnaces. George M. Eaton, Pittsburgh, Pa., assignor to Westinghouse Electric & Manufacturing Company.

A supporting apparatus for use in tempering furnaces comprising a base and three spaced supporting means carried thereby.

1,416,221. Connection for liquid-fuel burners. Gustave C. Lorenz, Milwaukee, Wis., assignor to A. J. Lindemann & Hoverson Company, Milwaukee, Wis.

A connection between the liquid fuel supply pipe and the burner of a liquid hydrocarbon stove comprising a member secured to the supply pipe and having an upwardly extending tabular portion, a tabular member connected with and extending downwardly from the burner, and telescoping with the said upwardly extending portion, an annulus of relatively soft material on one of said members, said annulus having beveled surfaces and adapted to act as a seal for the joint of the said telescoping members, one of the said members also having a beveled

portion in contact with the said annulus, the respective angles of the two beveled portions being different in degree.

1,414,614. Muffle furnace. Johannes Robert Carl August, Halifax, England. A rotary furnace of the rotary barrel type, formed by the combination of a rotary heating chamber closed at one end, and having a central aperture at the other, and a removable muffle or barrel inserted closed end first through the said aperture while the open end which is closed by a detachable cover is left projecting, the space between the rotary heating chamber and the barrel being subdivided by longitudinal bearers into a plurality of longitudinal flues for the hot gases to pass through, the bearers forming throughout their lengths supports for the muffle which rotates with the heating chamber.

1,422,572. Mold for hot-top ingots. S. E. Hitt of Elyria, Ohio, and J. I. Peyton of Chicago, Ill., propose an ingot mold whose topmost part is hollow cast.

A vacuum is maintained in this space and it is claimed that by this means the top part of the solidifying ingot will remain liquid much longer than the lower, thus acting as a sink-head to fill any pipe or contraction cavity which may be formed. A hollow-cast top may also be bolted to the top of an ordinary mold. Various precautions are mentioned concerning the manufacture of the mold, its design and the maintenance of the proper vacuum.

BRITISH PATENTS

178,107. Microscope condensers. C. Zeiss, Carl-Zeiss-Strasse, Jena, Germany. April 3, 1922 No. 9471. Convention date April 6, 1921. Class 97 (i).

The text of this patent refers to illustrations for purpose of description. A dark-ground immersion condenser for microscopes are constructed of two members *c, e*, of which the member *e* nearer to the source of the light is adjustable axially in relation to the other member *c* so that object slides of differing thickness may be used. The upper suface e^2 of the lower member is concentric with that of the lower surface of the lens *c*, being separated from it by an air gap. Light entering from below is reflected from the parabolic surface e^1 to the lens *c*, passing across the air gap substantially normal to the adjacent surfaces. Adjustment is effected by rotation of the lever *f* secured to the screwed mount *d* of the member *e*.

178,722. Furnaces. South Metropolitan Gas Co. and Chandler, D., 709, Old Kent Road, London. April 22, 1921, No. 11699 [Classes 51 (i) and 51 (ii).]

A gas-fired metallurgical furnace comprises a sloping floor 1 leading to a solid well-hearth 2, burners 4 being provided in the roof 3 and arranged at a tangent to the rear portion of the hearth. The products of combustion, after passing over the hearth, return in the opposite direction over the sloping floor to side flues 5, through which they pass to flues 6 arranged beneath the floor 1 so that the charge is preheated before it reaches the hearth. A skimming-door 9, having an inspection window 10, is provided at the front of the furnace and the hearth 2 is formed with a discharge spout 11 the passage to which is closed by a loose brick 12.

A DDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A repesents Associate Member; S represents Sustaining Member; J represents Junior Member, and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

NEW MEMBERS

ALLEE, H. DONALD, (M-9), 58 Delaware Ave., Detroit, Mich.
ANDERSON, O. L., (M-7), 3649 Canfield E., Detroit, Mich.
ANDERSON, GEO. A., (M-8), 1149 Hudson Ave., Detroit, Mich.
BEAUDRY, ROLAND, (M-8), 685½ Mineral St., Milwaukee, Wis.
BROWN, F. G., (M-8), Trumbull Steel Co., Warren, Ohio.
BURKET, H. D., (M-9), Bourne Fuller Co., Upson Works, Cleveland, Ohio.
CHAMBERS, A. A., (M-5), 225 32nd St., Milwaukee, Wis.
CHANEY, CARYL, E., (M-9), 97 Pilgrim Ave., H. O., Detroit, Mich.
COBLE, C. C., (M-5), 1540 Charles St., Rockford Ill.
CRAMER, HOWARD S., (M-8), 1421 S. Los Angeles St., Los Angeles, Cal.
EBERHARDY, W. W., (M-8), 377 Beulah Ave., Milwaukee, Wis.
FOLTZ, ROSS M., (M-5), 587 14th Ave., Wauwatosa, Wis.
FOREMAN, CHAS. L., (M-8), 1605 Stone St., Flint, Mich.
GRIES, GEO. G., (A-8), 1054 Book Bldg., Detroit, Mich.
HARTDEGEN, H. O., (A-8), 943 Book Bldg., Detroit, Mich.
HELLENBERG, CARL E., (A-5), 231 California Ave., Detroit, Mich.
HARRIS, F. E., (M-8), 205 W. Anne St., Flint, Mich.
HENNING, PAUL H., (M-5), c/o Detroit Screw Works, Detroit, Mich.
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FISCHER, G. H., (M-10), from 202 Maple St., Massillon, Ohio to Interstate Iron & Steel Co., 118th St., Plant So. Chicago, Ill.

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HUNNINGS, S. V., from Washington Steel & Ordnance Co., to 2826 27th St., Washington, D. C.

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WOLF, ERNEST, (Jr-6), from 3377 W. Congress St., Chicago, Ill. to Lewis Institute, Chicago, Ill.

ZORNIG, COL. H. H., from Watertown Arsenal to 305 Mt. Auburn St., Watertown, Mass.

(*Continued from page* 1221)

tems are the means by which costs may be reduced, quality raised and man's fallibility minimized.

Conclusion

The fixed charges of carburizing should and can be reduced to less than 1 cent per pound where there is steady production of standard parts and the total cost should not exceed twice the amount of the fixed or primary costs. This does not apply to carburizing operations in commercial steel-treating plants, of course, where production costs must be reckoned on a great variety of work and will vary from 3 cents per pound to three times that amount. But in cases such as referred to the ultimate cost of carburizing and heat-treating standard parts should not exceed 2 cents per pound if the proper methods and equipment are employed.

Commercial Items of Interest

Sir Robert A. Hadfield, Bart., president of Hadfields, Ltd., has been elected president of the Engineers' club of London, taking office Sept. 1 in succession to E. Manville, M. P., whose term expires,

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The Doehler Die Casting Co., Court and Ninth streets, Brooklyn, N. Y., has arranged for an increase in capital from $1,500,000 to $2,000,000.

The United States Civil Service Commission announces a competitive examination for the position of Associate Physicist qualified as a naval mine technician. Complete information regarding the qualifications for this position may be obtained from the Civil Service Commission at Washington, D. C., or from a civil service officer in any post office or custom office.

Further expansion has been decided on at the Cumberland, Md., plant of the N. & G. Taylor Co., Philadelphia. A larger power house is to be built with improved type of boilers, automatic stokers, coal handling machinery and the like. Additional capacity has been added to the tin house to meet the demand for roofing plate, the company being conspicuously a maker of tin and terne plate. All the open-hearth furnaces of the plant are reported in operation and the bar mill has been running day and night turns.

W. H. White, formerly connected with the United States Naval Ordnance plant, Charleston, W. Va., has been appointed superintendent of the open-hearth department Pittsburgh Crucible Steel Co., Midland, Pa., succeeding L. A. Lambing, resigned.

Thomas A. Wickenden and Charles McKnight, Jr., have recently joined the development and research department of the International Nickel Company, New York City, to undertake development work in connection with alloy steels. Mr. Wickenden was for many years associated with the Studebaker Corporation as Engineer in Charge at their South Bend Plant, and more recently associated with the Zeder-Skelton-Breer Engineering Company in a consulting capacity. Mr. McKnight was formerly Works Manager of the Carbon Steel Company and engaged for many years in the production of alloy steels.

Tate-Jones & Co., Inc., of Pittsburgh, are now building two rotating

hearth electric furnaces for the Continental Motors Corp., Muskegon, Mich., which will be used for the continuous heat treatment of connecting rods for motors. One furnace will be used for the quenching operation and the other for the draw-back.

The furnaces have a rotating hearth 22 inches wide and 7 feet 10 inches in diameter with charging and discharging doors at one side. The furnaces are heavily insulated and the heating element consists of ribbon resistors made by the General Electric Company placed on the side walls, having Leeds & Northrup control.

Celite Products, Limited, has been established in Canada to market Sil-O-Cel and Filter-Cel as produced by the Celite Company in the United States. Sil-O-Cel is widely used for the prevention of excessive heat loss from boilers, furnaces, etc., and is a very high efficiency temperature insulation. It is furnished in brick, block, powder, and cement forms and may be applied to all types of heated equipment without change in design. Filter-Cel is used as an aid in filtering to secure greater clarity and brilliance of filtrate. Its use reduces operating costs by increasing the rate of flow and by enabling the filters to operate in longer cycles. Stocks of these materials will be maintained in Montreal. Mr. Lawrence Russel has been appointed manager with offices in the New Birks Building.

Various grades of one brand of high speed tool steel made by the Firth-Sterling Steel Co., McKeesport, Pa., are described and their specifications given in a comprehensive booklet just issued. The maker calls attention to the many uses to which this steel can be put and points out the six factors to be considered in selecting high speed steels, namely, red hardness, density, minimum distortion, high heat treatment, price, and service and shipment. Each of these factors then is discussed in detail. Some 20 pages of the total of 44 carry a Centigrade-Fahrenheit conversion scale, a classification of standard sizes and extras and price quotations. This company has established the practice of publishing a booklet on each particular brand of steel manufactured in order that the user can find quickly in concise form all the available data about the brand in which he is interested. Three other booklets now are available.

Walter H. Haupt has recently joined the sales force of the Colonial Steel Company, Cincinnati, Ohio.

The Claude S. Gordon Company announces that they are now located at 708 to 714 West Madison street, Chicago. The Gordon Company specializes in heat treating furnaces, pyrometers and accessories including gauges, ther-

mometers and testing instruments.

The address of the New York office for Stewart Industrial Furnaces, which has been located at 350 Broadway since it was established early in 1920, has been changed to 16 Reade street. The office as before, is in charge of Mr. J. W. Lazear.

Vanadium-Alloys Steel Co., Latrobe, Pa., have issued a sixteen-page bulletin on the subject of non-shrinkable die steel with useful information regarding methods to be followed in its heat treatment.

The Westinghouse Electric & Manufacturing Co., Pittsburgh, Pa., have issued Leaflet No. 1824, describing arc welding on worn and broken brake shoes, bearings, frames, bolsters, etc. Illustrations showing methods are given as are also figures showing the savings possible in reclaiming worn out parts.

Dr. Geo. K. Burgess who was elected President of the American Society for Testing Materials at its annual meeting, is chief of the Division of Metallurgy of the Bureau of Standards and has been connected with the Bureau since 1903. Dr. Burgess has long been prominent in many of the engineering and scientific societies and has written many scientific papers. Recently he was elected a member of the National Academy of Science and has been a representative of the American Engineering Standard's Committee for the Department of Commerce since the organization of the Standard's Committee. He is vice chairman of the iron and steel committee of the American Institute of Mining and Metallurgical Engineers; a member of the engineering division and of the division of research extension of the National Research Council; chairman of the joint committee on the investigation of sulphur and phosphorus in steel; and a member of the National Research Council's correlating committee on corrosion. As chairman of the metals committee of the Federal Specifications Board he has been actively concerned with the question of unifying government specifications for metals. Dr. Burgess was born at Newton, Mass., Jan. 4, 1874, and was graduated from the Massachusetts Institute of Technology in 1896. He taught physics at the Massachusetts Institute, at the University of Michigan and at the University of California prior to his joining the Bureau of Standards. In 1901 he wrote "Recherches sur la Constante de Gravitation" and at that time in Paris was made a doctor of science. Some of his more recent publications relate to thermal stresses in chilled iron and steel car-wheels and the properties of special steels containing zirconium and other elements; tests of centrifugally cast steel; government research; the government laboratory and industrial research. Dr. Burgess is a member of the American Society for Steel Treating.

A program for laboratory work to be conducted at the Bureau of Standards (following the views expressed in the committee meetings) has been prepared and distributed to the members. Several valuable comments on the program have been received to date.

The first laboratory work undertaken has been to determine the reliability of the Amsler wear test machine. This work is being conducted by Mr. Freeman and assistants of the Metallurgical Division. Tests discs for this machine of S. A. E. 1020 steel case-hardened and S. A. E. 1090 steel hardened were made up by Pratt and Whitney Company. The case-hardened discs flaked in the machine and were consequently not suitable for determining its performance. As it is difficult to harden carbon tool steel uniformly, an oil-hardening steel, "Ketos," was made up into discs, hardened and used for preliminary tests of the machine. Difficulty was encountered in aligning the machine but has been corrected. However, sufficient data are not yet available to report definite results.

As the progress of the wear tests has been rather slow, arrangements have been made with Dr. Mathews, of the Crucible Steel Company, to get a supply of 1.10 carbon-1.40 chromium-steel for hardening experiments and wear tests and of 0.45 carbon steel for testing the wear of hard discs against soft. As the chromium bearing steel is at present the most universally used gage steel, it is planned to make the most elaborate tests on it.

While waiting the receipt of appropriate steels for the study of hardening problems, some quenching experiments have been made to determine the characteristic curves, cooling power, and reproducibility of the common quenching media; this was accomplished by finding calorimetrically the average temperature of a standard nickel cylinder after different times of immersion in the quenching bath. Cooling curves were thus obtained for quenching in water at 30 degrees Cent. with and without motion of the cylinder, for quenching in oil at 30 degrees Cent. without motion and with slow and fast motion of the cylinder, for quenching in oil at 10 degrees Cent., 100 degrees Cent. and 200 degrees Cent. without motion of the cylinder, and for cooling in still air. The problems in heat treatment are being investigated by Mr. Scott assisted by Mr. S. S. Kingsbury of the Metallurgical Division.

Mr. French has varied the heat treatment of several steels in the form of 4-inch cylinders similar to those recommended by the committee with the principal object of determining the effect of rate of heating on the dimensional changes. Some of these cylinders showing large dimensional changes on hardening are being measured for time changes.

The length measurements are being made under the immediate direction of Mr. Miller of the Gage Section. This section has also prepared an attachment to the millionth comparator to take 4 to 0.03 inch blocks for measuring the changes on hardening and with time. The attachment includes an

oil bath in which the specimens are partially immersed to secure temperature uniformity.

Industrial gas men will be interested in the announcement just made by the Chicago Flexible Shaft Co. of Chicago that it has taken over the sales of the Selas company. Having been engaged for 26 years in the successful building and selling of Stewart furnaces, the Chicago Flexible Shaft Co. has decided to give its clientele an added service by not only supplying furnaces but by furnishing economic devices for their operation.

The Selas system is based on the well known theory that, through partial premixing of gas and air, complete combustion can be secured and positively maintained under varying conditions of gas supply and material treated. We understand that it is installed at present in over 600 industrial establishments throughout the country, the names of which form the industrial blue book of the United States.

It is pointed out that the Selas system is applicable to every kind of industrial use to which gas is put. The manufacturer declares that it can be controlled to the *n*th degree and has the added advantage of saving a large percentage of gas.

The Selas company was organzed about 12 years ago, but during the war it was taken over by the alien property custodian and sold to the present owners. The plant was moved from New York to Philadelphia and the business expanded through a sales organization of their own. The Chicago Flexible Shaft Co., having a national organization of the same kind of engineering sales, is well equipped to take hold of this device and give it a wide distribution.

The Chicago Flexible Shaft Co. has established a school at its own plant for the education of its salesmen in the operation and sales of the Selas system. The engineers of the Selas company at present are taking a trip throughout the country visiting all of the Chicago Flexible Shaft Company's agencies and instructing them in this system. This is another step taken by the Chicago Flexible Shaft Co. to give its present customers and future patrons an added service that will increase the use and efficiency of gas for all industrial purposes. An active sales campaign is now being made on this well known combustion device.

F. J. Ryan & Co., Philadelphia. Pamphlets, Common Sense Talks Nos. 1 and 2 on "Electric Heat; What Is It"? and "The Electric Resistor."

Scientific Materials Co., Pittsburgh. Generously illustrated. 16-page booklet, 6 x 10 in., giving a scientific exposition on the theory, design and use of the F. & F. pyrometer, and including a Fahrenheit-Centigrade conversion table, formulas governing pyrometer construction, and tables for determining the true when given the apparent temperature.

Transactions of
American Society for Steel Treating

Volume II | SEPTEMBER, 1922 | Number 12

Published monthly by The American Society for Steel Treating at Cleveland, Ohio.
All communications should be addressed to

AMERICAN SOCIETY FOR STEEL TREATING
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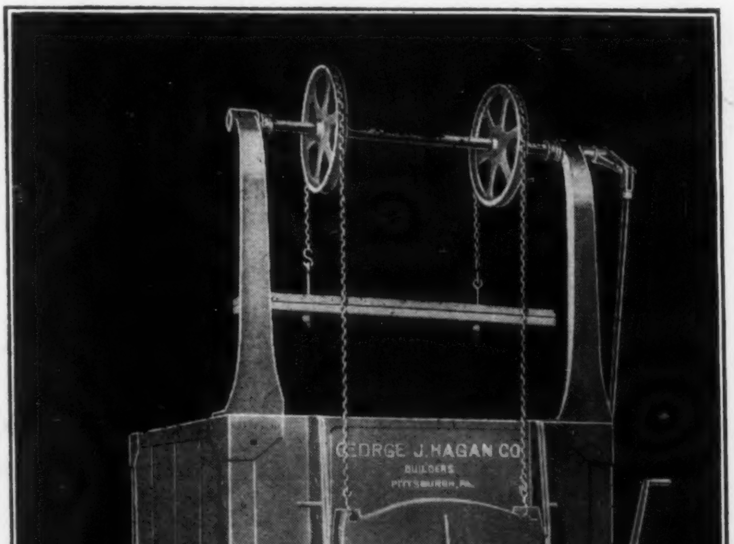

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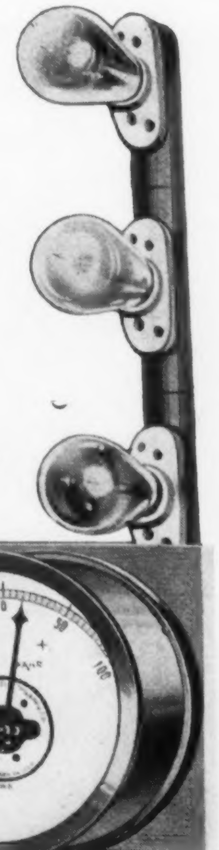

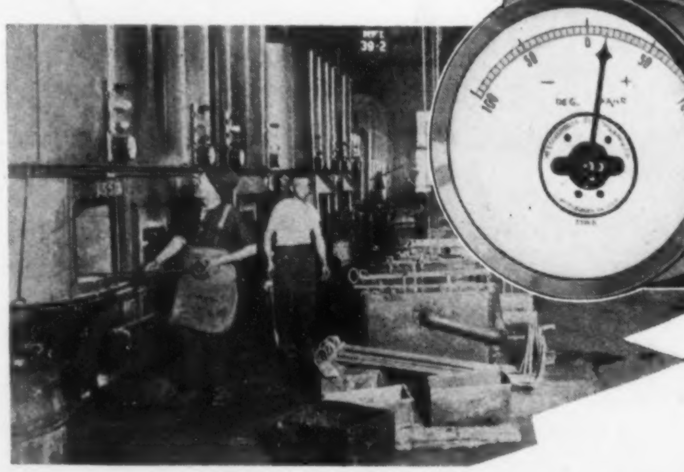

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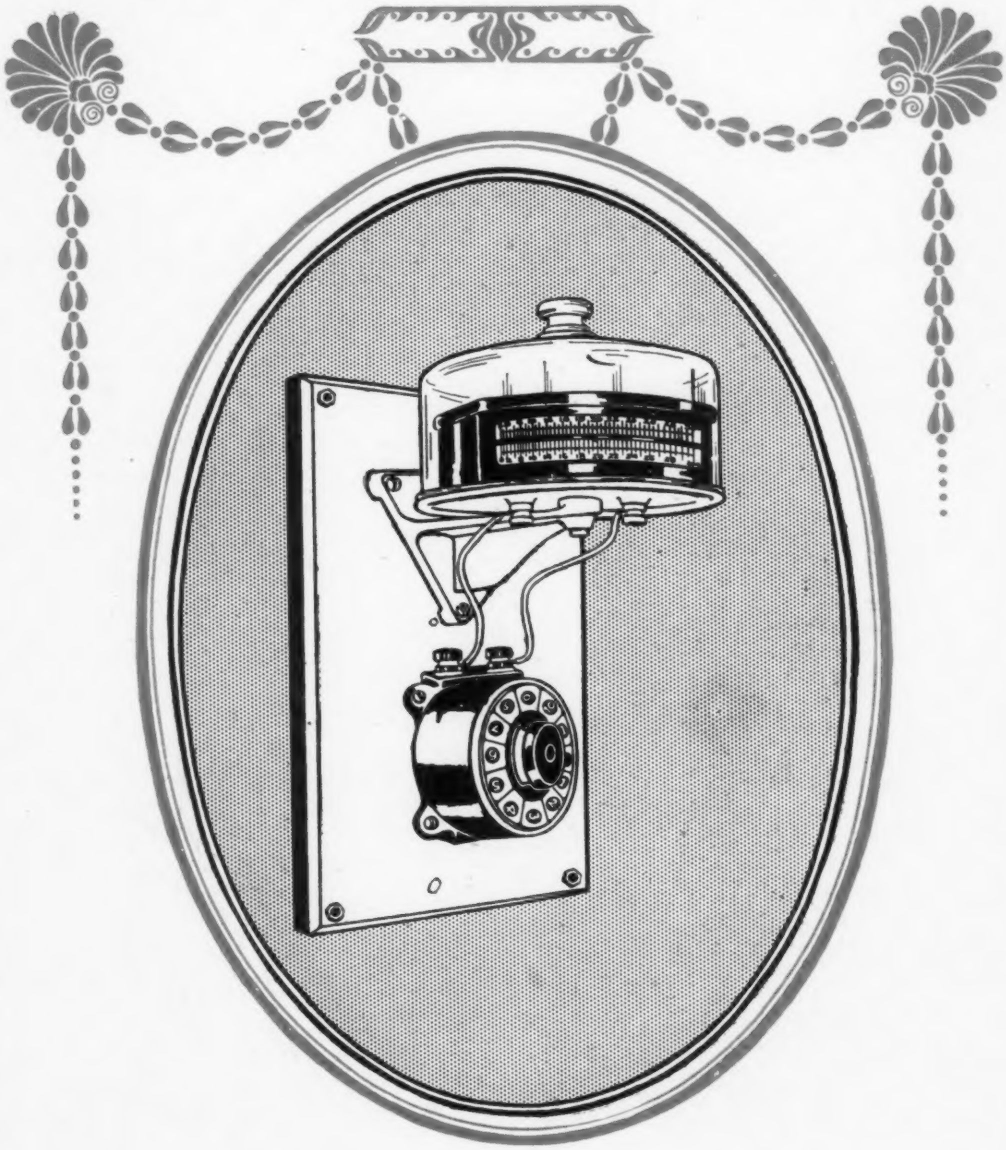

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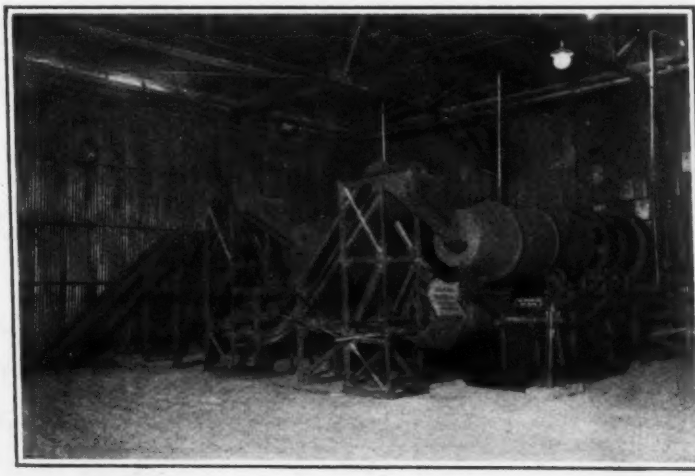

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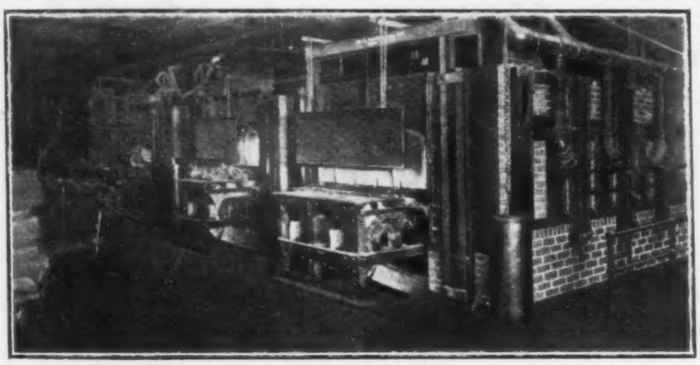
It also has the advantage of ***increasing output*** **in proportion to labor, fuel and floor space, as one man with an automatic furnace can do more work, at less cost, than two or three men with a furnace operating on the "batch" principle.**



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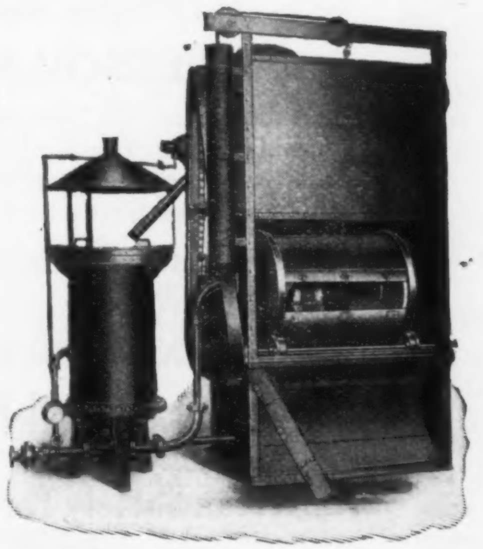

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For Removing Scale After Heat Treating

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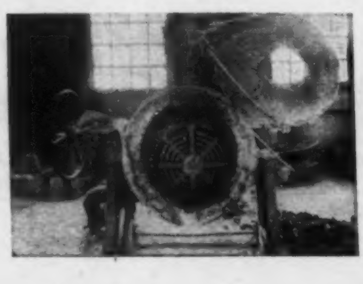


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—your letter hits the nail on the head! CALITE Castings ARE BEST where exposure to high heat conditions is necessary.

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Send for these samples—Two thirds size Test Them Yourself

A request on your letterhead will bring either of these two pieces of cast CALITE. An actual test will prove more than pages of printed argument.

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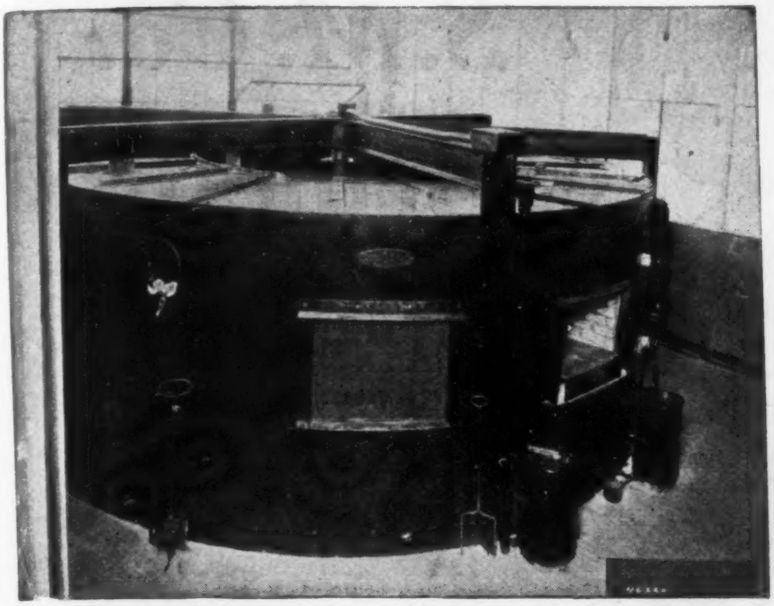

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Saving of 90% in time and production may be effected in making a repair.

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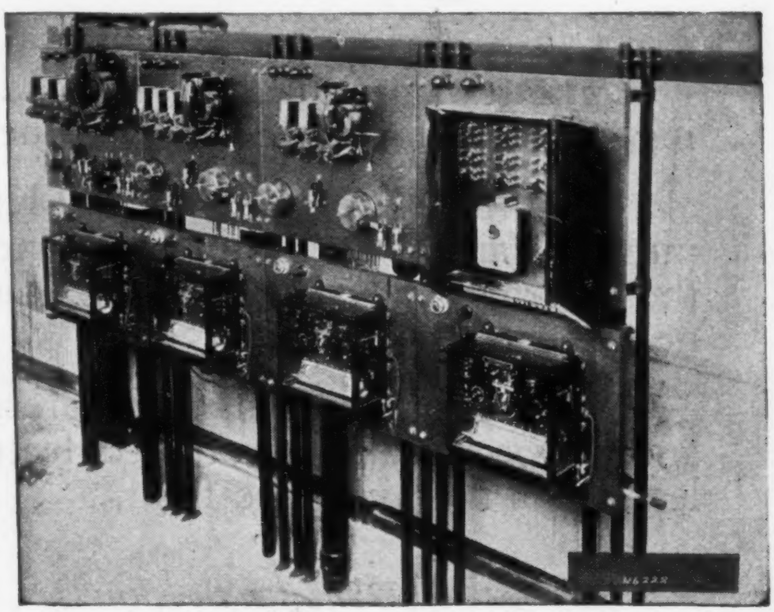

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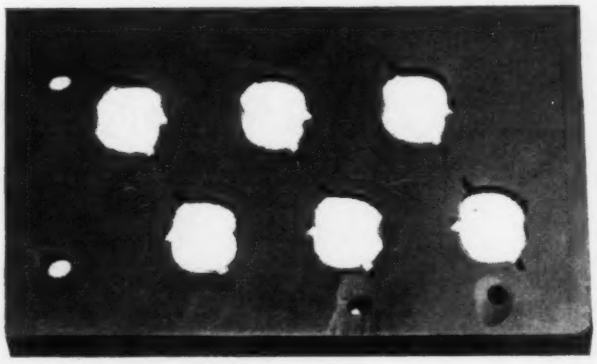

Another job done well with COLONIAL

102,000,000 pieces produced by this die— and still going strong

SIX impressions at each stroke, 200 times a minute —1200 pieces punched out every sixty seconds by this die, till it has now passed the total of one hundred and two million—and ready for the same job over again.

It turns out about 500,000 pieces a day (making full allowance for all misses of stroke) and keeps at its work steadily day after day.

For all this production the die has been ground only six times.

It is made of Colonial Special No. 14 Tool Steel.

To all who are interested we are glad to authenticate this record, to give the name of the plant, the conditions, and full particulars of the work.

The task of this die is not altogether exceptional; rather it is simply another record of the many types of every-day work done well with Colonial.

For the jobs that are hardest, and the runs that are longest, there is always a Colonial Tool Steel to fulfill the need.

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IT ELIMINATES

Costly cleaning operation after heating in lead, *because* work comes out ***clean.***

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Send for sample.—It will verify our statements.

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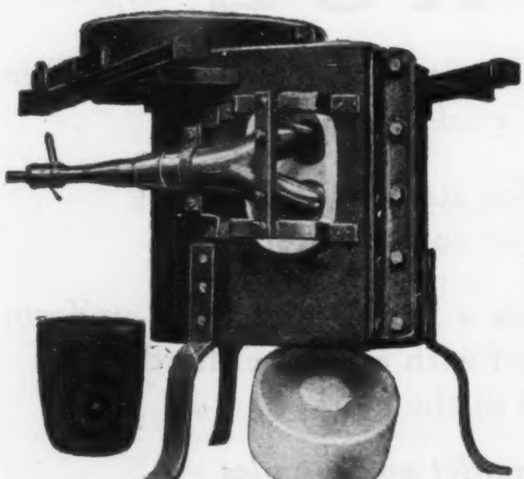

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brass, nickel, iron, copper, silver, gold, Palladium, alloys, etc.
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Besides these are more than 250 other types and sizes, covering every variety of heat treating operation in practically every industry.

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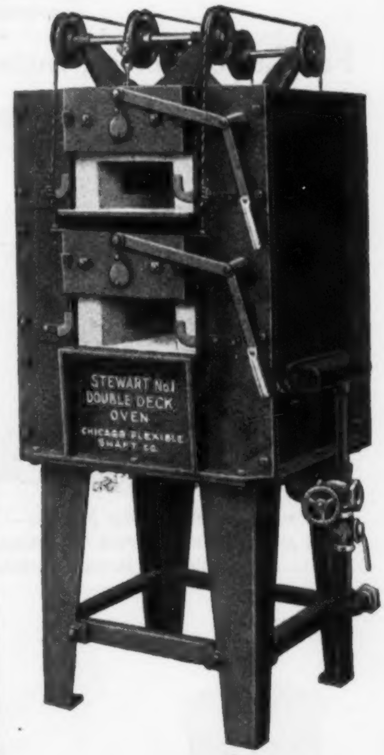
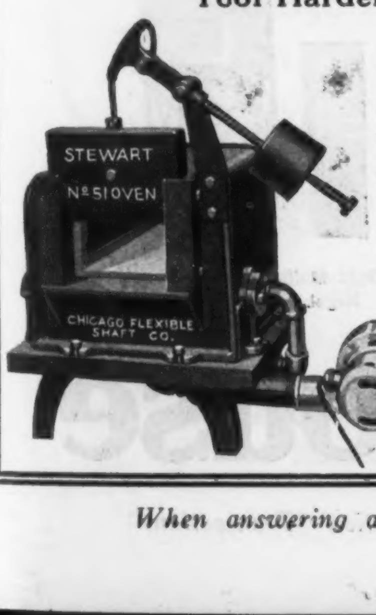


A Double Deck Furnace for High Speed and Carbon Steels

Upper chamber heated by waste gases from lower chamber. Lower chamber fitted with carbofrax hearth and supports for high heats.

Five standard sizes.

Splendid Shop Accessory for Tool Hardening



This Stewart No. 51 is a wonderful little general purpose furnace. Indirect heat type. Equipped with carbofrax U-shaped slab. Handles a wide range of small tool hardening and similar work up to its capacity. Placed on a bench anywhere. As shown, equipped complete with motor-driven blower.

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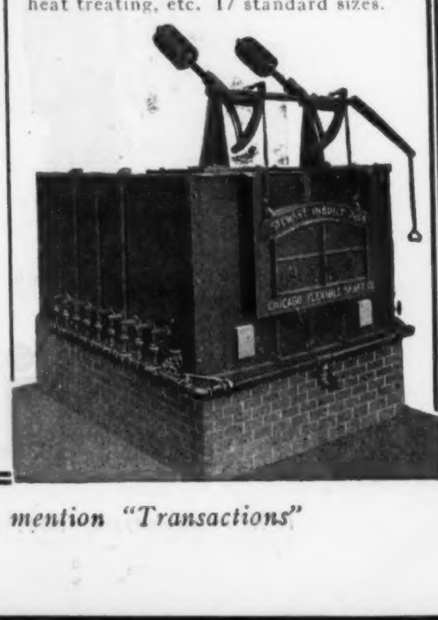
For permanent installations. Large capacity for annealing, carburizing, heat treating, etc. 17 standard sizes.



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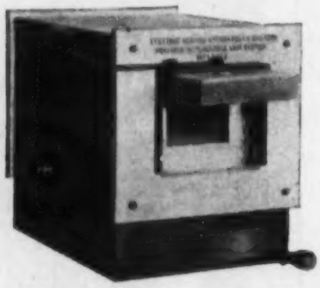
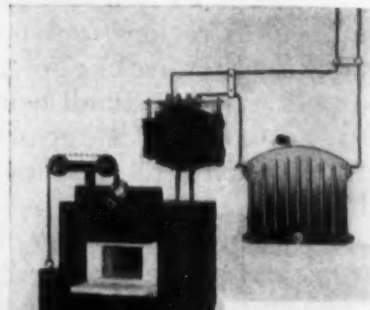
For Laboratories, Instrument Manufacturers, Tool Shops, Etc.

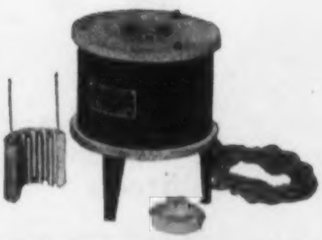
Temperatures up to 2000° F.



Incased-Rheostat Muffle Furnace — Types 60, 62, 64 and 66. Door, Shown Top-Hinging, is Reversible for Bottom Hinging



Type HD92 Muffle Furnace Complete With Transformer and Controlling Rheostat



Crucible Furnace, Types 80, 82, 84 and 86—Shown with One Spare Unit

This form of furnace is used extensively for melting small quantities of base metals; for pyrometer calibration when couples are immersed in molten salts or metals; and for decalescent work in steel.

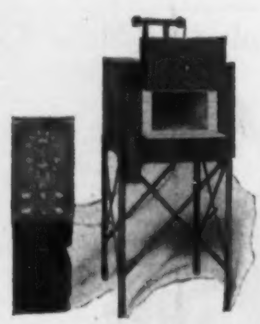
Standard Combustion Tube Furnace Type 77

Shown with one spare unit, height to center 10"

Combustion Furnace, Hinged Design Type 70

Shown with one spare unit, height to center 9¼"

Type HD710 Crucible Furnace with Regulating Transformer



Type HD122 Muffle Furnace Complete with Regulating Transformer

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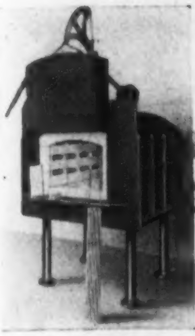
Large Hevi-Duty Industrial Furnaces

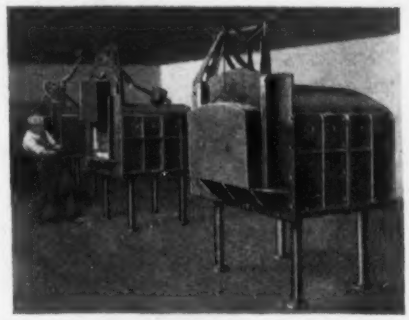
For Any Kind of Heat-Treating Process

Any Size — Any Capacity — Temperatures up to 2000° F.



Type HD2631
Single End, 25 x 16 x 36'

A six-strand return bend coil placed in three muffle plates shown on floor, leaning against shelf of furnace. At the left on furnace shelf is shown grooved muffle plate. Also on the shelf is shown a Tee-support. These return-bend coils, muffle plates and Tee supports are typical of all catalogued sizes. Two muffle plates, each 12 inches long, comprise the length of the 24-inch furnace; three muffle plates in the 36-inch furnace: four in the 48-inch furnace.



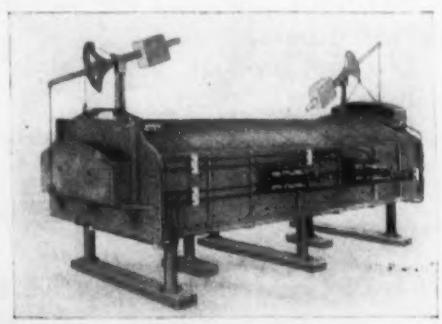
Battery of Industrial Types of Furnaces (Standard Sizes.) From Left to Right Respectively, Types HD1321, HD1331 and HD2631

Figure the Guaranteed Efficiencies at Your Operating Temperature, and Compare Operating Costs With Any Other Furnace—Oil or Electric, on the Market

		Inside Dimensions			Rising to 1800 Deg. F. K. W. From Room Temperature			K. W. per Hour Holding at		
Type	Style	Width	Length	Height	Full Load	Time	K. W. Hrs.	1400° F.	1600° F.	1800° F.
HD1321	Single End	18	24	13½	22.66	3⅕ hr.	75.5	3.8	4.5	6.2
HD1331	Single End	18	36	13½	29.88	3¼ hr.	97.1	4.3	5.7	7.4
HD1341	Single End	18	48	13½	40.60	3¼ hr.	131.9	4.7	6.1	8.2
HD1361	Single End	18	72	13½	57.75	3¼ hr.	187.7	6.4	8.2	11.0
HD2631	Single End	25	36	16	35.86	3⅓ hr.	119.5	5.1	6.7	8.5
HD2641	Single End	25	48	16	48.72	3⅓ hr.	162.4	6.4	7.9	10.4
HD2661	Single End	25	72	16	69.30	3⅓ hr.	231.0	8.5	10.3	13.8
HD3641	Single End	32	48	16	56.84	3¼ hr.	184.7	7.4	8.6	10.8
HD3661	Single End	32	72	16	80.85	3¼ hr.	262.8	9.9	11.7	15.1
HD1362	Double End	18	72	13½	57.75	3⅓ hr.	192.5	7.4	10.4	13.7
HD2662	Double End	25	72	16	69.30	3½ hr.	242.5	10.0	12.0	15.7
HD3662	Double End	32	72	16	80.85	3⅔ hr.	296.5	11.7	13.8	17.8

Westinghouse
Electric
Furnaces

See our Exhibit at the September Convention



Double-End Furnace, Inside Dimensions, 44 in. Wide, 12 ft. Long, 6 in. High to Spring Line of Arch, 10 in. to Center of Arch, Capacity 120 Kilowatts.

Westinghouse Electric & Manufacturing Company

East Pittsburgh, Pa.

Westinghouse

Note the corrosion on this alloy pot luted with clay. It has the same furnace life as the pot shown on the right. Several more heats and then it must be discarded.

This alloy pot luted with Sealright and having the same furnace life as the one on the left is as good as new. Note the absence of corrosion. Its life is indefinitely prolonged. Thus by actual demonstration Sealright proves itself.

Multiply container life—

Sealright is the ideal life prolonger

Use it on new alloy pots to prevent corrosion. Also on old alloy pots previously corroded by clay luting—it will prevent further corrosion.

A clay luted box is restricted to a limited life far below its capacity. A Sealright-luted box attains its full life.

Sealright assures complete protection against corrosion of alloy boxes, regardless of the carbonizing compound used.

Sealright prevents the possibility of clay fusion, and soft spots on the treated parts.

No spoilage of material. No re-treatments of expensive parts. Absolute dependability.

Used in the same manner and as easily as clay.

Our laboratory tests prove the foregoing claims: Practical use by many consumers confirm them: A trial by you will further establish the advantages of Sealright.

Rodman Chemical Company
Verona, Pa.
Detroit, 105 Manistique Street
Pacific Coast Representatives
Waterhouse & Lester Company—Los Angeles—San Francisco—Portland

SEALRIGHT

—The New Luting Material—

U-LOY STEELS

Why you can expect service from us

One good reason is pictured below, namely, our blast furnace. Its capacity of 500 tons daily insures a steady supply of pig iron—an important factor in the prompt filling of orders.

A monthly production of 50,000 tons of ingots is made possible by 22 open hearth furnaces, 4 electric furnaces and 3 blooming mills. Our Heat Treating and Cold Drawing Departments are complete in every detail. In their entirety our plants cover a total of 410 acres. With such facilities at hand backed by our 19 years experience in steel making, we are prepared to give the best of service to manufacturers.

Besides, competent metallurgists are ready to assist you in determining which U-LOY steel is best suited to the manufacture of your product,—no matter what it may be.

UNITED ALLOY STEEL CORPORATION
CANTON, OHIO

New York	Chicago	San Francisco
Syracuse	Detroit	Indianapolis
Cleveland	Buffalo	Portland

Open Hearth and Electric Furnace U-LOY Steels are furnished in:—

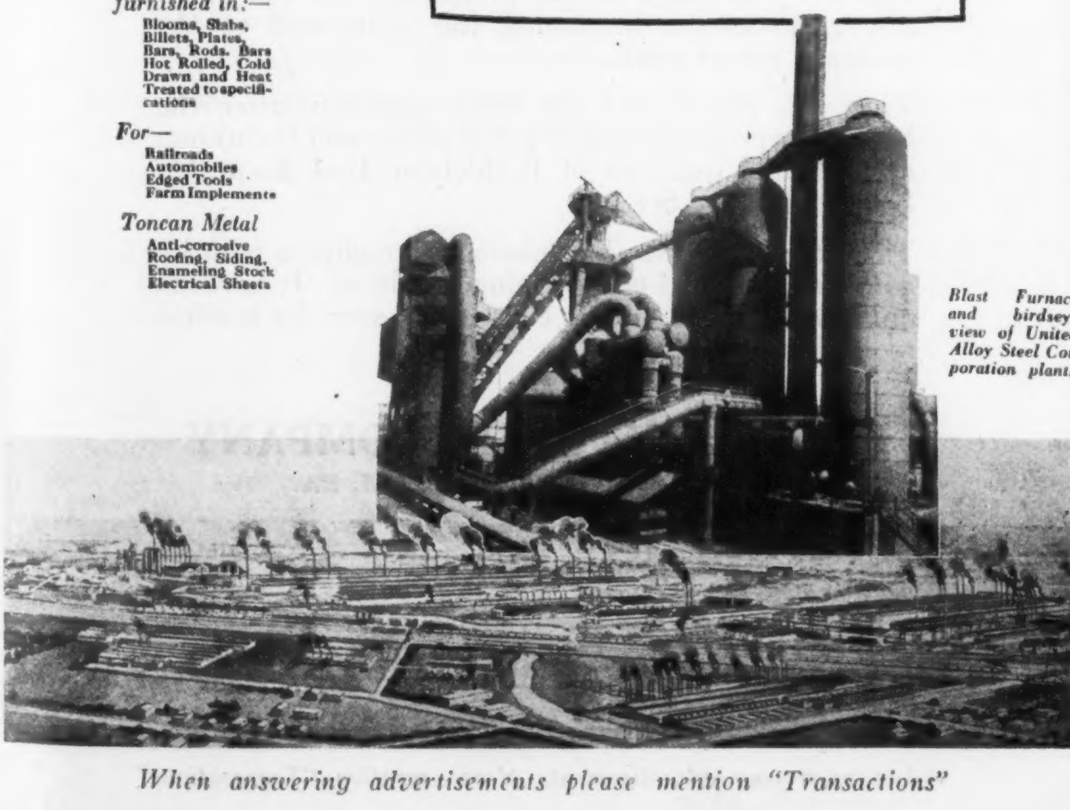
Blooms, Slabs, Billets, Plates, Bars, Rods. Bars Hot Rolled, Cold Drawn and Heat Treated to specifications

For—

Railroads
Automobiles
Edged Tools
Farm Implements

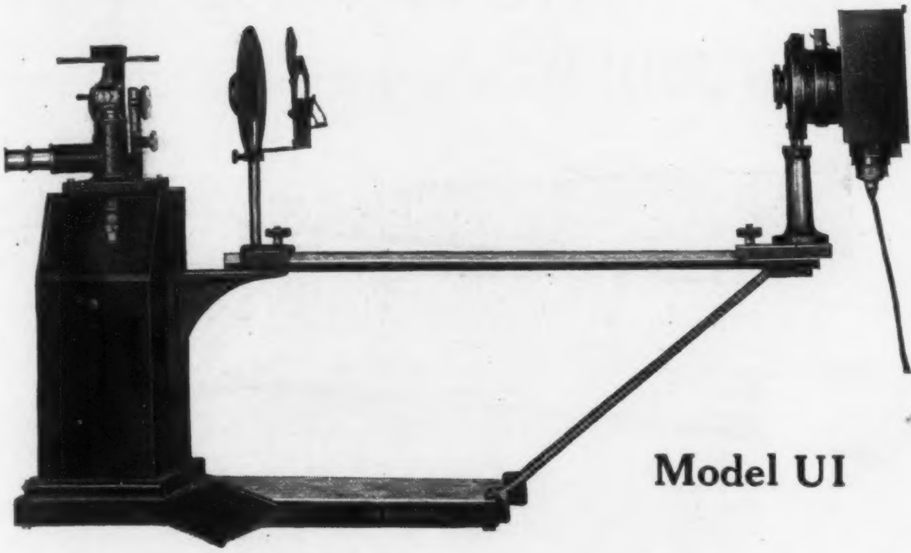
Toncan Metal

Anti-corrosive Roofing, Siding, Enameling Stock Electrical Sheets



Blast Furnace and birdseye view of United Alloy Steel Corporation plants.

Optics in Steel Treating



Model UI

In the Bausch & Lomb booth at the Detroit convention you will find a complete display of Metallurgical Microscopes and Metallographic Equipments, essentials of major importance in every steel treating laboratory.

There will also be on exhibition one of the Contour Measuring Projectors, by means of which the contour of screw threads, gear teeth, cutting tools, etc. can be accurately checked and measured to detect errors in cutting tools, machine set up, or distortion from hardening.

Our representatives will be very glad to demonstrate any of this equipment to you, and to show you how you can advantageously use it.

Bausch & Lomb Optical Co.

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Leading American Makers of Metallographic and Photomicrographic Apparatus, Microscopes, Photographic Lenses, Projection Apparatus (Balopticons), Ophthalmic Lenses and Instruments, Range Finders and Gun Sights for Army and Navy, Searchlight Reflectors, Stereo-Prism Binoculars, Magnifiers and Other High-Grade Optical Products.

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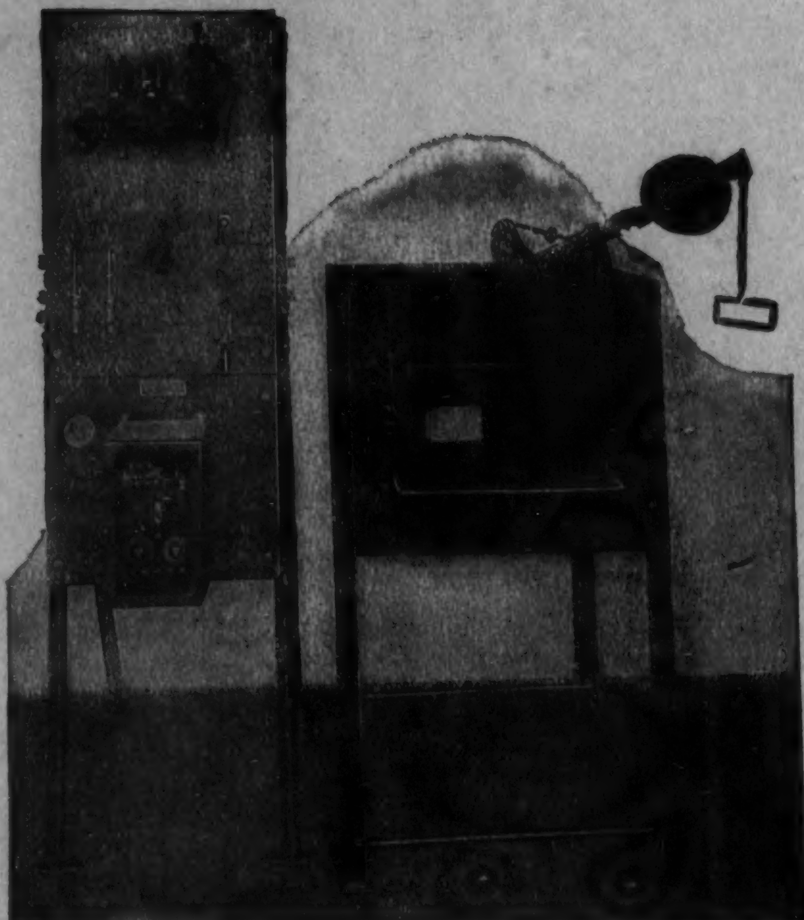

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